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REVIEW OF WORLD ENGINEERING PROGRESS

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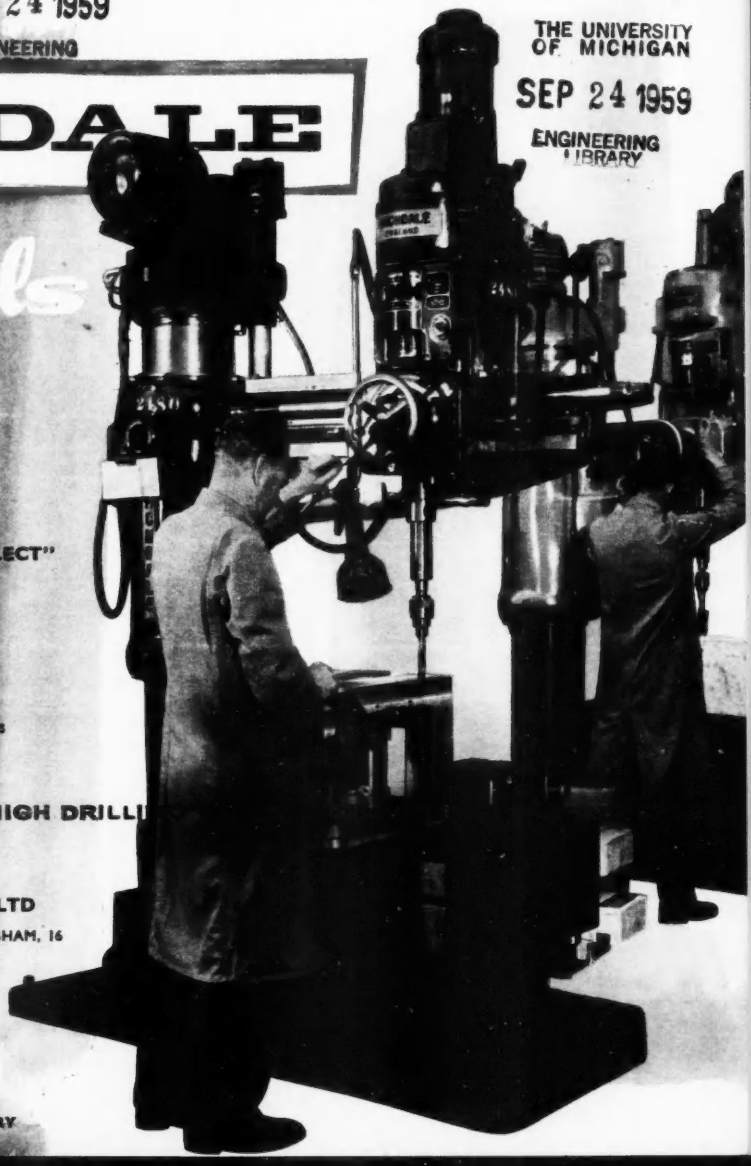

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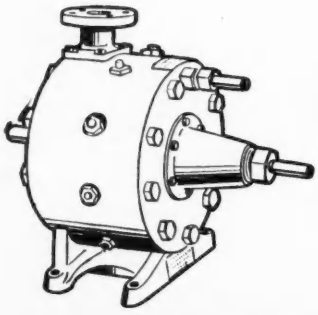

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THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *ELIMINATING SINTERING IN FLUIDIZED BEDS*

Tests have shown that, in a fluidized bed of sand, the particles tend to sinter when a fuel containing sodium and/or vanadium is burnt at a temperature higher than that at which the ash formed during combustion fuses or softens. Generally, sintering phenomena in a sand bed occur at temperatures of 600°C and above, but they do not occur at a temperature as high as 900°C, provided that the sodium content (calculated as sodium oxide) is less than 0·03%, or the vanadium content (calculated as vanadium pentoxide) is less than 0·1%. Apparently, a layer of softened ash forms around the particles of the finely divided refractory material, interfering with fluidization, while the formation of lumps may in some cases entirely prevent fluidization. According to a recently patented process, it is now claimed, however, that sintering of the particles can be reduced or prevented, even with appreciably high sodium or vanadium contents, by introducing into the bed one or more compounds of the metals in Group III of the Periodic Table, the most effective being magnesium oxide or magnesium naphthenate, zinc oxide, calcium oxide, and aluminium oxide. The compound can be introduced by dissolving or suspending it in a liquid which is then injected or sprayed into the bed, or by the simple method of injecting it in a finely divided form entrained in a gas, e.g., some or all of the combustion air or gas used to fluidize the bed itself. As an example of the improved results obtained with this technique, tests have been carried out on sand already containing ash formed by the combustion of a liquid fuel with a 0·1% content of sodium, heated for 5 hr at 900°C. When no additive was used, the sand sintered but, when 0·5% aluminium oxide, magnesium oxide, or zinc oxide was added to the sand, sintering was prevented. Similarly, in the case of a liquid fuel containing 1·06% sodium, the sand sintered when heated for 5 hr at 900°C without an additive, but sintering was prevented when the sand contained a minimum of 3% magnesium oxide or 10% aluminium oxide or zinc oxide.

● *HIGH-FREQUENCY SEAM-WELDING OF TUBES*

In recently patented equipment for high-frequency seam-welding of tubes, particularly continuous seam-welding, the tube is advanced past a point where pressure is applied to close the gap of the preformed tube, so that the gap is closed at the point of welding. Electrodes are provided which contact the tubing on or near the gap edges and at a position shortly in advance of the welding point, a high frequency electric current of not less than 10-kcs frequency being supplied to the electrodes. A core of electrically non-conductive magnetic material, positioned inside the tubing to impede the flow of high-frequency current circumferentially around the tubing, is located in a tubular housing which is liquid-cooled internally. With this equipment the amount of heat at the welding point can be readily controlled by moving the magnetic core longitudinally with respect to the position of the electrodes and the welding point. Furthermore, by adjusting the position of the core, the amount of internal upset of metal at the weld in the tube can be controlled. In other words, by varying the position of the core, the current flowing adjacent to the gap edges to be welded can be varied in such a way that the paths of maximum current flow are more or less closely confined to the edges, thus varying, the degree of internal upset of the metal along the line of the weld. Generally speaking, if the core is placed in a more widely spaced position from the gap edges, the internal upset of the metal may be less or negligible and, if the core is brought up closer to the gap edges, there will be a larger amount of internal upset. The most desirable adjustment of the position of the core in this respect may vary for tubing of different metals and of different thicknesses and may be determined by trial. On thin-walled steel tubing in particular, it is possible to make a complete weld of the opposed gap edges without causing any very broad heat pattern along the edges.

● *IMPROVED METHODS OF MAKING SEMICONDUCTOR DEVICES*

Methods of encasing a semiconductor device in a glass envelope containing a significant impurity are known, but usually the embedding process is conducted at such a temperature that diffusion of the impurity into the semiconductor material is insignificant and the electrical properties of the semiconductor are not really affected. It is now claimed, however, that this difficulty can be obviated by a recently patented method which includes the steps of applying a glass-forming composition containing a signi-

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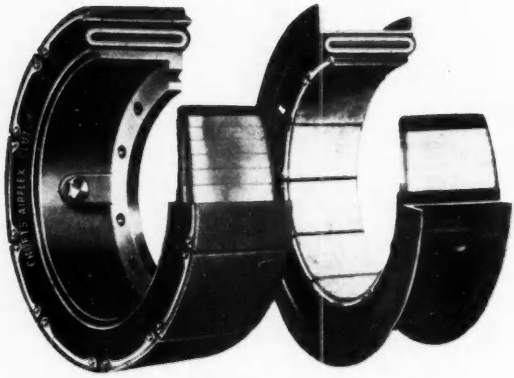

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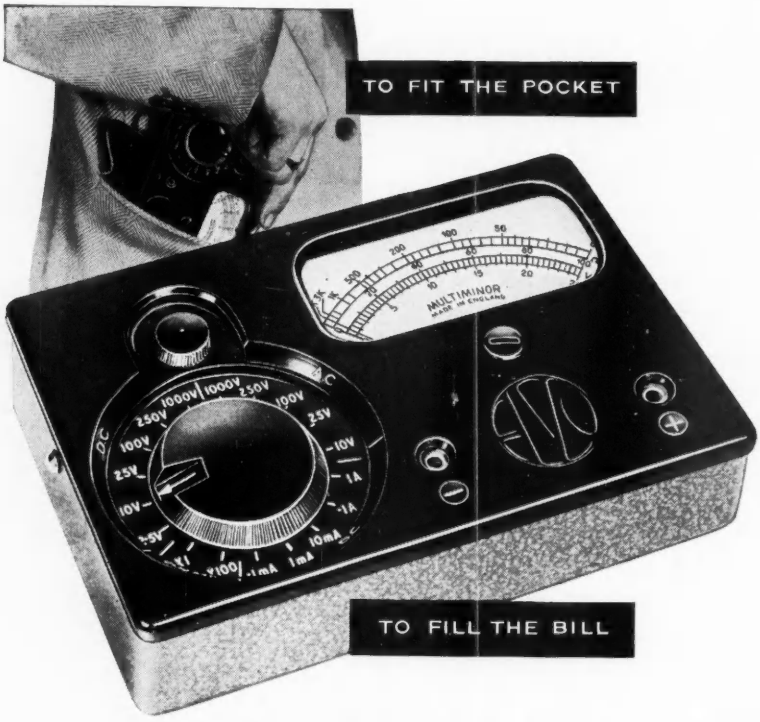
ficant impurity to the surface of the semiconductor body, and then at least partially fusing the composition at an elevated temperature, so as to diffuse the impurity into the surface of the body wherever the composition has been applied, thereby altering the conductivity or conductivity type of the diffused surface. At the same time, the composition forms a protective coating on the semiconductor. The composition can be so chosen that the coating is transparent and can be made either as an insulator or conductor, by adding finely divided metal to it. In the latter case, the coating not only acts as the impurity source, but also provides an ohmic connection to the body. For the formation of adherent glassy coatings on the surfaces of the semiconductors, the thermal-expansion characteristics of the glass compositions used should be nearly similar to those of the semiconductors; otherwise, chipping and cracking of the glaze may occur after cooling. Application of the glass to the semiconductor surface can be effected in various ways, sprinkling or dusting of the ground glaze constituents being particularly effective in cases where only a flat upper surface of a plate or disc is to be coated. In general, almost any easily handled compound of a donor or acceptor element is adaptable to the technique, though oxides have proved especially convenient for use in forming glasses. Thus, coating compositions made with oxides of boron, aluminium, gallium, indium, or tantalum can be used successfully to form *p*-type layers in *n*-type or intrinsic conductors, while coatings containing oxides of phosphorus, arsenic, antimony, or lithium can convert intrinsic or *p*-type material to an *n*-type.

● *IMPROVED "DUPLEX" CHROMIUM PLATING*

It is claimed that thicker chromium, plated as a "duplex" deposit, will give automobile bumpers and other trim parts a bright finish with much better corrosion resistance than has been possible in the past. The new plating method consists of an initial application of bright crack-free chromium plate for optimum coverage and build-up in low-current-density areas. This is followed by a second bright deposit of finely cracked chromium. This duplex chromium plate, with a total thickness of 0·0001 to 0·0002 in., is applied over suitable undercoats of copper-bright nickel on die-cast zinc or steel parts. The corrosion of bright-plated automobile components, which has caused so much concern, is due to rapid pinhole rusting and blistering, attributed to electrolytic cell action. This type of corrosion is a "stripping" action, in which the rate of penetration and removal of metal depends on the cell potential. The higher the cell potential, the more rapid is the rate of stripping, manifesting itself in faster corrosion. Since electroplated metals do not normally bridge defects, a few isolated spots corrode rapidly, because all the cell potential is concentrated at these defective spots. However, when a finely cracked chromium layer is deposited on top of a crack-free chromium layer, the rate of corrosion is markedly reduced, and this is ascribed to the fact that the presence of many cracks over the entire surface disperses the cell action over a large area. There is therefore a substantial reduction in current density at each of these individual openings. As a result, the current density is kept below the value corresponding to the critical potential needed for anodic perforation of the underlying metals. Although it is more difficult to protect zinc-base die-castings than steel, the new duplex chromium process is reported to produce an improvement in corrosion resistance of 100% or more on regular production-run die-castings.

● *INFLATABLE SEAMLESS METAL TUBING*

A new type of thin-walled seamless tubing, supplied in the form of a ribbon which is then inflated to shape when required for use, has been developed, and experimental production will shortly be initiated. The obvious advantage of this type of tubing lies in the fact that it can be supplied economically in compact rolls or reels which can later be unreeled, expanded, and cut to length. The possibility of using it to make corrosion-resistant linings for pipes and tanks is also envisaged, the ribbon being inserted into a pipe or tank and then inflated to form an inner liner. Other potential applications include its use as irrigation piping, as electrical conduit, and as a packaging material for frozen foods, toothpaste, etc. Furthermore, when constructed of special metals, such as stainless steel, zirconium, titanium, tantalum, or columbium, it may prove of importance in the manufacture of light-wall, seamless rocket and missile bodies. The first step in the manufacture of the tubing is to form by conventional techniques a simple hollow shape which is then passed through a rolling mill, where it is flattened into ribbon form, the rolling process elongating the original tube by making it thinner, without, however, changing the inside tube diameter. The diameter of the tubing can range from about $\frac{1}{16}$ in. up to 6 ft and more; in fact, the diameter is limited only by the size of the starting piece, whose size, in turn, is limited only by the capacity of the mill. The walls of the tube can be as thin as foil or as thick as those of conventional pipes, and the tubing can be supplied in coil lengths of as much as 15,000 ft. Inherent in the tubing produced by the rolling process is a pair of ribs or fins on the outside. These provided added stiffness in the case of thin-walled tubes, but can, if desired, be removed during forming.



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The equipment used for inflation will probably vary with the dimensions of the tubing and its application, but inflation by hydraulic or pneumatic pressure appears to be a simple method. Once inflated, the material can be cut to length by any conventional means.

● *LOCATING DAMAGED REDUCTION-GEAR TEETH*

A device has been developed which makes it possible to locate damaged reduction-gear teeth by fixing the position of the damaged tooth in relation to a timing bump installed at a known position. This device is particularly useful because, in large reduction gears such as those used in marine propulsion plants, there are a great number of teeth on different gears rotating at different speeds, and thumps from damaged gear teeth are often difficult to locate because of the noise transmitted through the gear casing to other parts of the unit. Moreover, after the noisy gear has been located, tedious trial-and-error methods are sometimes required to find the damaged tooth. The operating principle of the new device is based on the use of two vibration pick-ups feeding simultaneously through amplifiers into a two-channel oscillograph. One of these pick-ups is placed against the gear casing and records, on one channel of the oscillograph, the vibration, or thump, resulting each time a damaged tooth on a gear meshes with the teeth of its mating gear. The other pick-up takes its excitation from a once-per-revolution timing bump, which is mounted on the rotating gear element under surveillance at a known location where it will not damage the teeth. The vibration set up by this bump is recorded on the second channel of the oscillograph. Thus, the position of the thump caused by the damaged tooth is recorded on one channel of the oscillograph, and the position of the once-per-revolution timing bump is recorded on the other channel. By simple subtraction of relative position, the location of the damaged tooth can be found in relation to the timing mark on the gear, and tests have shown that damaged areas can usually be located by this method within a band width of two or three teeth.

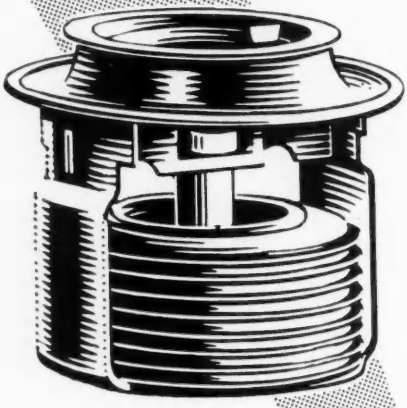
● *APPLICATIONS OF SILICON NITRIDE*

Like other natural or artificial refractory materials, silicon nitride has excellent resistance to oxidation and corrosion at high temperatures. Unlike many other materials, however, it also has good mechanical properties at temperatures up to 1200°C. In applications where silicon nitride is not required to stand severe stresses, it can be used at temperatures up to 1650°C, in contact with a neutral or reducing atmosphere. This favourable combination of properties has resulted in silicon nitride being considered for the parts of rocket nozzles which have to attain a high temperature, the resistance of the material to erosion by products of combustion making it especially suitable for this application. Silicon nitride is also finding an increasing use as a refractory lining for furnaces for melting non-ferrous metals and as a sheathing for thermocouples used for measuring temperatures up to 1200°C. In this connection, perhaps the most unusual property of silicon nitride is its immunity to attack from many molten non-ferrous alloys, in particular unalloyed aluminium, making it particularly useful in thermocouple sheaths for measuring the temperature of molten aluminium. Silicon nitride is not wetted by many molten non-ferrous metals, and this property has led to its use in crucibles for some of the rarer metals, including the manufacture of zone-refined germanium metal used as a semi-conductor. Silicon nitride may be mixed with a binder to make a refractory ramming mix. Fabricated parts can also be made by a special process which involves principles of both ceramics and powder metallurgy.

● *ELIMINATION OF HYDROGEN FLAKING IN HEAVY FORGINGS*

Hydrogen is known to be responsible for flakes in heavy forgings; as, however, it is generally believed that a small residual hydrogen content in steel is inevitable, heat treatment is resorted to in order to prevent flaking. Although time-consuming, heat treatment controls flaking quite well, and, though flakes occasionally appear, on the whole it is possible to produce sound forgings. However, a high hydrogen content also has an adverse effect on the tensile ductility of the material. This has become a matter of considerable concern with the increasing size and alloy content of heavy forgings, and failures of forged shafts of steam-turbine generator units have naturally served to stimulate efforts to eliminate this dangerous situation. Probably the most widely known defect associated with high hydrogen content in heavy forgings is thermal flaking, and flakes naturally cause much concern, since their presence in large forgings means outright rejection. Heat treatment applied to prevent flaking usually consists of an annealing, normalizing, and tempering, or a double normalizing and tempering cycle. Because of the large masses involved the time required for a simple normalizing and tempering treatment generally runs from five to

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.



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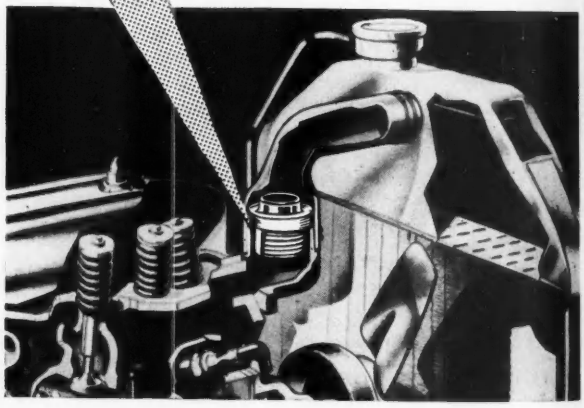

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ten days. To prevent flaking, however, additional slow cooling, isothermal holding, and normalizing and tempering cycles are often employed, and these can extend the total heat-treating time to as long as 40 days. Investigations have shown that these difficulties can be overcome by the use of the vacuum-casting process, in which the hydrogen content can be kept significantly below the potential limit attainable by the closest control of conventional melting. Rotor forgings produced from vacuum-cast ingots have been found to exhibit a hydrogen content throughout their cross-section of about 1 part per million, without any indication of hydrogen segregation, and experiments have shown that rotor steel from vacuum-cast heats could not be flaked by the most severe tests. Moreover, all forgings showed only insignificant differences in ductility between aged and unaged tension tests.

● *APPLICATIONS OF THE MICRO-ENCAPSULATION PROCESS FOR LIQUIDS*

The micro-encapsulation process makes it possible to encase droplets as small as 1 micron in diameter in a thin shell of gelatine or other suitable film-forming material. The resulting capsules, which handle like flour and which may almost be termed " dry liquids ", resemble one-cell micro-organisms and can be made to respond to light, perform memory functions, enclose oils, dyes, and highly reactive chemicals, or to form " dry-wet " lubricants. In effect, encapsulation permits compounds to be intimately mixed without premature reaction; only when they are ruptured, e.g., by heat or pressure, are their contents released, allowing reaction to take place. The first commercial use of these micro-capsules was in the manufacture of a " carbonless " duplicating paper, which employs two different compounds, i.e., an activated clay and an encapsulated dye. Since then, many other applications have been found and many others are being considered. Thus, for example encapsulation can solve problems of incompatibility in the formulation of special lubricants by keeping sensitive materials separated until friction or heat ruptures the capsules and permits the desired reaction to take place at the time lubrication is required. Similarly, the fabrication of plastics can often be simplified by premixing the resin and a catalyst in capsule form, so that they remain inert until pressure or heat is applied. Another application is in the formulation of special-purpose paints for extremely adverse conditions, such paints frequently being based on reactive materials which combine shortly before their use. By encapsulation, these materials can be combined at the factory, eliminating waste caused by deterioration and providing better quality control. Similarly, in the case of adhesive of the epoxy-and phenolic-resin types, which are mixed with catalysts just prior to use, encapsulation makes it possible to premix these materials, capsule rupture taking place only at the time and place desired. Pressure-sensitive adhesives can also use the same principle. Thus, tacky resins on tapes can be replaced by non-tacky coatings of encapsulated material, which becomes adherent only when pressure is applied.

● *HIGH-TEMPERATURE GLASS-FIBRE LAMINATES*

It is reported that glass-fibre laminates capable of withstanding temperatures in excess of 1000°F, with a strength-to-weight ratio comparable to that of steel and insensitivity to thermal shock, are now in an advanced stage of development. These laminates consist of glass fibres bonded in a silica-based matrix, the direction of the threads greatly influencing the properties of the final product and allowing for unlimited combinations. Each layer can have a different type of winding, and metal or organic fibres can be wound in with inorganic fibres. To permit winding in various directions, a textile yarn-winding machine can be used, and a seemingly endless variety of winding patterns can be produced, while the internal structure of the article and its strength and flexibility can be controlled. The range of potential applications covers such widely diversified products as coffee-pots, missile fuel-tanks, missle nose-cones, pipes for hot corrosive liquids, and filters. In addition to its excellent strength-to-weight ratio, this new inorganic laminate exhibits remarkable resiliency. Fibre density can be controlled, and strength bears an almost linear relationship to density. In flexure tests, samples have been found to fail in compression, while the fibres in tension were unaffected. Of all forming methods considered, the filament-winding technique has achieved by far the best results. In this technique, continuous fibres are wound on a mandrel shaped to the desired inside contour of the part. The matrix material is then applied to the fibres by a brush during the winding operation, followed by drying and firing of the part. High-strength parts can also be formed by a gluing technique, involving the coating of the fibres in the form of fabric or rovings with the matrix material in a colloidal suspension and then joining them together.

For a further selection of items, please see our "Minidigest" section on pages A2, A4, and A6.

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The Saga of Oil

By

Alexander Howard

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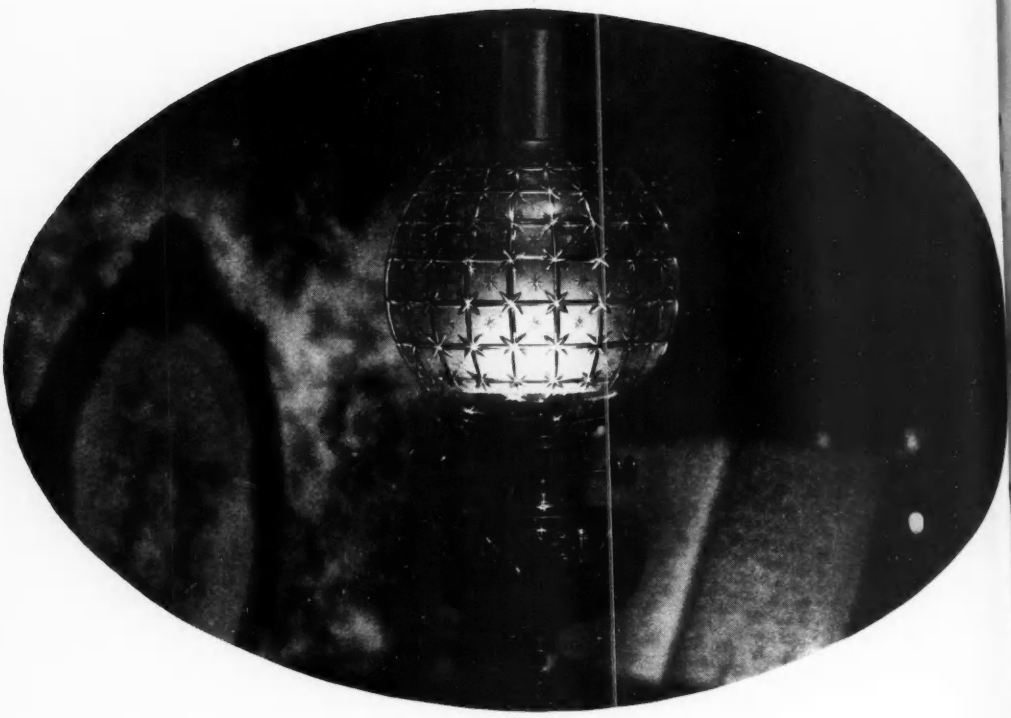

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The Saga of Oil

By Alexander Howard

Introduction

Probably the most striking fact about the oil industry is its comparative youth. Most of the giant companies that make up the vast empire of oil were founded after 1880—well within the lifetime of a great many people still active to-day, and, except for the discovery of crude petroleum and the gathering of a few facts about its basic properties and uses, all the essential developments in the petroleum industry have taken place within the first half of the present century.

Yet the whole tapestry of modern living standards is conditioned by an abundant supply of oil and its derivatives as the great purveyor of the world's energy requirements. The extent of this may be easily gauged by the bare fact that the global consumption of oil now exceeds 500,000,000 Imperial gallons every twenty-four hours of the day, year in year out.

Oil has firmly entrenched itself as the paramount fuel; it has made modern transport possible by powering the world's cars, lorries, aeroplanes, tractors, and many other vehicles. Practically all ocean-going ships are now oil-fuelled and the world's trains are more and more being driven by diesel locomotives, both by reason of smoother operation and the possibility of longer runs without the need for refuelling.

Motorized farm implements have proved an inestimable boon to higher and easier agricultural production, and every draft animal released by a machine has freed enough land from raising animal fodder to feed four people. Indeed, agricultural experts have estimated that the farmer can now produce an acre of wheat with one-thirtieth of the man-hours expended by a farmer on the same job one hundred years ago, using hand tools.

Moreover, mechanized farming has eliminated a great deal of irksome and backbreaking " stoop labour ", and the successful application of machines to ploughing, harrowing, sowing, fertilizing, cultivating, pest-controlling, and hauling have brought the glittering prospect of abolishing hunger from the face of the earth within the grasp of mankind.

Oil through the Ages

Oil has, of course, existed below the surface of the earth since time immemorial, and the weathering action of sun and wind produced pitch from the crude oil that had seeped to the surface of the earth through fissures. Mention is made in the Bible of the use of bitumen (better known as coal tar) by the builders of the Tower of Babel. Noah's Ark was pitched inside and outside, while the basket in which Moses was found in the bulrushes by the daughter of Pharaoh was also caulked with pitch.

Then there were the mystical and awe-inspiring " Eternal Fires " in the Baku region on the shores of the Caspian Sea, for centuries devoutly worshipped by the ancient Persians. These mysterious fires were really nothing more than the seepings of petroleum gas and oil which had become ignited after escaping from the earth.

There are also records of bitumen having been used in Southern Persia as long ago as 6000 B.C., and the bricks made by the Sumerians in Mesopotamia at least 4000 B.C. are known to have been bonded with bitumen. Many centuries later Nebuchadnezzar waterproofed the stone of his fabulous hanging gardens with bitumen, and Nimrod's famed winged lions, now a greatly prized treasure in the British Museum originally stood on a layer of bitumen.

In more recent times, Marco Polo described in A.D. 1271 the use of oil for anointing camels afflicted with mange.

The ever-ingenious Chinese, when drilling for salt water, often found oil floating on it as a sort of scum, which they collected and used for the preservation of ships' ropes. Moreover, in the process of extracting salt from the brine by evaporation, they used the oil to fuel their fires. Nearer home, the peasants of Roumania applied oil seepages for medicinal uses as long ago as 1646.

There is evidence, too, that petroleum was used by the natives before Columbus arrived in America and, when in 1629 the early Jesuit missionaries reached the great inland basin of the Ohio River, Indians led them to natural springs of petroleum and showed them pits in the valley of what later became known as Oil Creek in Pennsylvania.

Some of the pits in Oil Creek were from six to eight feet square at the mouth and, in some instances, twelve feet deep. Many were yielding oil when the first white man appeared there, and natural gas bubbled on the surface of the streams of the Ohio Valley. Early travellers in those regions have recorded that they had been guided to the virgin oil territories by the Indians, who, setting the natural gas on fire, worshipped the weird flames with pagan awe and veneration. The Jesuits reported that the springs contained " heavy and thick water, which ignites like brandy, and boils in bubbles of flame when fire is applied to it ".

One of the most remarkable early references to petroleum in north-western Pennsylvania is to be found in a 1768 entry in the " Diaries of Zeisberger Relating to the First Missions in the Ohio Basin ". Zeisberger, a Moravian missionary, records that four of his companions, who had gone on a hunting trip down the Allegheny River, " brought back some oil from the oil wells. There are said to be various such wells in this region. The oil has a very strong odour and cannot be used with food. The Indians use it externally as a medicine and it would be possible to use it for lighting. The oil comes out of the ground with the water and then rises to the top, so that it is possible to skim it. The Indians generally try to get that which has just come up, as it has no pungent aroma. The nature of these oil wells might well be investigated ".

But it took some ninety years before a New York lawyer by the name of George B. Bissell and his associates began to " investigate " the possibilities of these wells.

The World's First Oil Company

It was mediaeval scientists who first used the term " petroleum ", the Latin word for " rock-oil ". The earliest record of the existence of petroleum in Pennsylvania is Lewis Evans's " Map of the Middle British Colonies in America ", produced in 1755 in London, on which the word " petroleum " appeared across the very territory in which a century later the oil springs, destined to become the cradle of the oil industry, were located. Again, in 1791, there appeared a map of Pennsylvania, on which for the first time figured the name " Oil Creek " for a small stream; ever since, all maps of Pennsylvania have mentioned Oil Creek.

Around the early part of the nineteenth century, Dr. James Young, a Glasgow chemist, had been investigating oil seepages in Derbyshire, and eventually, after a laminated rock, known as oil shale, was discovered in Scotland, he succeeded in 1847 in extracting from it " paraffin ".

But the credit for the idea of exploiting oil commercially by drilling is generally accorded to a man by the name of Samuel M. Kier, of Pittsburgh, Pennsylvania. Kier was, in fact, after brine when, drilling in 1848 on the banks of the Allegheny River, Pennsylvania, he accidentally struck oil which floated to the surface of the salt water from his father's salt wells near Tarentum, Pennsylvania. From this accidental discovery sparked the idea of drilling for oil itself.

Kier, an owner and operator of canal boats between Pittsburgh and Philadelphia, used the oil he found primarily for medicinal purposes, and to some extent also as a fuel for lamps. He sold his product in small medicine bottles labelled " Kier's Petroleum or Rock Oil. Celebrated for its wonderful curative powers. A natural remedy. Produced from a well in Allegheny County, 400 feet below the Earth's Surface ". With a great sense of showmanship and a bent for exploitation, Kier made an elaborate display in the window of his newly opened drug store, featuring prominently alongside the bottles of his " Rock Oil ", put up in eight-ounce bottles wrapped in flamboyantly worded circulars, notices describing the wonderful properties of his product in these poetic terms:—

The healthful balm from Nature's secret spring,
The bloom of health, and life, to man's well being;
As from the depth the magic liquid flows,
To calm our sufferings, and assuage our woes.

The circular contained detailed instructions as to the medicinal applications of the oil. Apart from recommending it as an all-round liniment, its value was stressed against such ills as cholera, liver troubles, bronchitis, and consumption—the dose prescribed being three spoonsful a day!

Prominently displayed in Kier's shop window was the now legendary pseudo $400 bank-note, drawn on the " Bank of Allegheny River ". An outstanding feature of the bank-note was a picture of a derrick which was supposed to represent the well. The bank-note stated that the issuer, Samuel M. Kier, while drilling for saline on the bank of the Allegheny River in 1848, had found oil at a depth of 400 feet.

Just about this time, around 1853, a young New York lawyer, George H. Bissell, visited his former teacher and friend, Dr. Dixi Crosby, of the Dartmouth Medical School, at Hanover, New Hampshire. Dr. Crosby, happened to show him a small bottle filled with a dark, thick fluid, saying it was a medicinal oil found in many places in Pennsylvania, and used for curative purposes by some people, and as an illuminant by others. That particular bottle, he told Bissell, had come from the Hibbard farm owned by the lumber firm of Brewer, Watson & Co., of Titusville, Pennsylvania. Crosby also told his friend that, in his opinion, the liquid was suitable for " refining " to be used as a superior lamp oil, with great commercial possibilities.

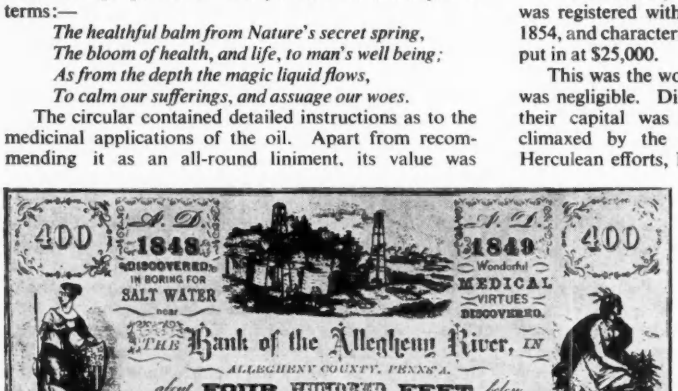
The seed of this idea fell on fertile soil, but what really fired Bissell's imagination was Kier's famous bank-note advertisement, which he happened to come across just at that time.

According to tradition, Bissell is said to have walked down Broadway when he stopped for a moment to enjoy the shade of an awning before a drug store, and there his eye caught sight in the window of a bottle of Kier's Rock Oil, but it was particularly the illustration of the derrick that captured his imagination.

Bissell decided then and there that the way to get oil, and plenty of it, was by drilling, and drilling deep. He wasted no time in contacting Mr. Brewer at Titusville and, with his law partner Eveleth, speedily made arrangements for the purchase of the Hibbard farm for $5000 on the understanding that a company would be organized forthwith to develop it.

In due course, the Pennsylvania Rock Oil Company was registered with a capital of $250,000, in December 1854, and characteristically the land bought at $5000 was put in at $25,000.

This was the world's first oil company. But progress was negligible. Differences arose amongst the partners; their capital was dwindling and their troubles were climaxed by the financial slump in 1857. Despite Herculean efforts, Bissell and Eveleth could not sell the


400
A. D.
1848
DISCOVERED IN BORING FOR SALT WATER
A. D.
1849
Wonderful MEDICAL VIRTUES DISCOVERED.
400
THE Bank of the Allegheny River, IN
ALLEGHENY COUNTY, PENN'A.
about FOUR HUNDRED FEET below the Earth's surface, is pumped up, with the Salt Water, flows into the Cystern, floats on top, when a quantity accumulates, is drawn off into Barrels, is bottled in its natural state without any preparation or admixture. For particulars, get a Circular.
400
Pittsburgh.
400
P. M. Kier.
400

Kier's pseudo $400 bank-note, issued in 1882 to advertise the medicinal properties of mineral salts, showing derricks and tanks of the type eventually used in the early oilfields.
(Courtesy of the Drake Museum, Titusville, Pa.)

stock, so much so that the company was dubbed " The Fancy Stock Company ", and there came a time when they could not even pay their hotel bill in New Haven.

In their straits they approached James M. Townsend, a local banker, and Bissell is recorded to have told him wryly, " Just think of it, here we are with property worth millions, and we are about to be thrown out of our hotel because we can't pay our board! "

Mission to Titusville

Prior to all this trouble, Bissell had sent for analysis a sample bottle of Kier's Rock Oil to Professor Benjamin Silliman Jr., of Yale University, at that time America's foremost analytical chemist, who, after an investigation lasting over four months, summarized his findings in an impressive report. Some further delay ensued because Silliman had been unwilling to hand over his report before his fees, amounting to $526.08, were paid. Finally, Eveleth personally raised enough money to pay the bill and received the report in the autumn of 1855. Thus, the first scientific analysis of rock oil, which was destined to prove a crucial factor in the establishment of the petroleum industry, was held up for weeks for the paltry sum of $526.08.

The analytical report concluded with these words: "It appears to me that there is much ground for encouragement that your company have in their possession a raw material from which by a simple and not expensive process they may manufacture very valuable products. It is worthy of note that my experiments prove that nearly the *whole* of the raw product may be manufactured without waste, and this solely by a well-directed process which is in practice one of the most simple of all chemical processes."

Meanwhile, Bissell and Eveleth had been finding it almost impossible to sell stock in the New York company. Times were altogether very difficult and there was a general distrust of the enterprise. Moreover, under the existing laws of the State, a stockholder became personally liable for the debts of his company. Bissell and Eveleth therefore ultimately decided to abandon this company and to promote a new company in Connecticut, where stockholders had no such liability to face. Thus was born the Pennsylvania Rock Oil Co. of Connecticut, with the co-operation of Townsend.

Silliman's favourable report provided a powerful fillip and eventually, after a great deal of company juggling by Bissell and Townsend, yet another company was formed in March 1858 under the name of the Seneca Oil Co. of Connecticut. The name Seneca was chosen as it seemed to the promoters to carry a certain amount of goodwill, because in very early times oil springs were known to have existed in the vicinity of Lake Seneca, in the interior of what is now the State of New York. The Indians used this oil as a liniment; later, it began to be used quite extensively by white people, too, for various bodily ills, and gradually became known as " Seneca Oil ".

It was on the introduction of Townsend that a man by the name of Drake, to whom Townsend had on an earlier occasion sold $200 of stock in the Oil Company was appointed general agent of the company at the annual salary of $1000, with instructions to proceed to Titusville, Pennsylvania, to start oil-producing operations, and with $1000 placed at his disposal for this purpose.

Edwin Laurentine Drake was a man of sparse education and knew nothing about drilling. He had successively been an Erie canal-boat captain, a farm labourer, a hotel clerk, an assistant in a drug store, an express agent, and finally a railroad conductor on the New Haven railroad, on which, after his retirement, he happened to make the acquaintance of Townsend.

When Drake arrived in Titusville in May 1858, it was a dilapidated village, 350 miles west of New York, consisting of some 150 people of all types. To impress the local inhabitants Townsend made it a practice to send frequent letters addressed to " Colonel " Drake—an altogether unwarranted title, but one which stuck to him ever afterwards. Whether because of the spurious title so adroitly conferred upon him by the astute Townsend, or because of his own bearing and manner—he invariably wore a stovepipe hat and frock coat—Drake certainly succeeded in impressing the people of Titusville.

He has gone down in history as Colonel Drake, the man who actually drilled the well which opened up the priceless treasure of a tremendous new liquid source of power and, in doing so, started almost instantaneously the overwhelmingly rapid development of what is now the world's most fabulous industry.

The development of the technique of producing oil is one of the major contributions made by U.S. enterprise to world progress and, though tough and determined men of many nations have assisted in building up the vast international oil industry to what it is to-day, it was in modest little Titusville where it all began.

Drake Strikes Oil

Drake began his drilling operations by putting up a 35-ft. tower made of wooden slats, with a pulley and a rope for raising and lowering the drilling tools. The tower came to be known as a " derrick ", supposedly derived from the name of the famous Tyburn hangman of early seventeenth-century England.

Drake used the technique applied by the Chinese thousands of years before when drilling for water, in which a hole was driven into the ground by repeatedly lifting and dropping a heavy cutting tool suspended from a rope and known as the " bit ". A 6 hp steam engine in an adjacent shed, fed by a wood-burning boiler, provided the power for this percussion-drilling operation.

From the very start, Drake was beset by all manner of difficulties: He was unable to find suitably experienced men for drilling; he could not hire men willing " to work for a lunatic "; he was unable to obtain the proper implements required for the job, and, above all, his money was rapidly dwindling away, as the Seneca Oil Company was unable, or unwilling, to provide him with further funds.

Things were going badly; weary months went by and the local chorus of jeering became louder and louder. People began to refer to the project as " Drake's Folly ", and it speaks volumes for Drake's imperturbable tenacity and persistence that, in the teeth of all this, he was able to persuade two Titusville citizens to accept his personal note for $500 to enable him to carry on with the project.

After months of disappointments, Drake finally found an experienced salt-well driller in April 1859, in the person of William A. (" Uncle Billy ") Smith, a blacksmith, who had made drilling tools for salt wells in his unpretentious little smithy at Tarentum.

He and his son agreed to join Drake and drilling began in earnest in May 1859, but weeks flew by without success. The main trouble was that, owing to the soft nature of the ground, the hole continually caved in as

Photograph of Drake (*right*) with William ('Uncle Billy') Smith, taken in front of his well in 1861, two years after the flow of oil had ceased. (*Courtesy of the Drake Museum, Titusville, Pa.*)

soon as it was drilled. Even Uncle Billy was baffled and said to Drake: " For thirty years, man and boy, I been drillin' hereabout, but I never seen the beat o' this. It's like drillin' into sawdust."

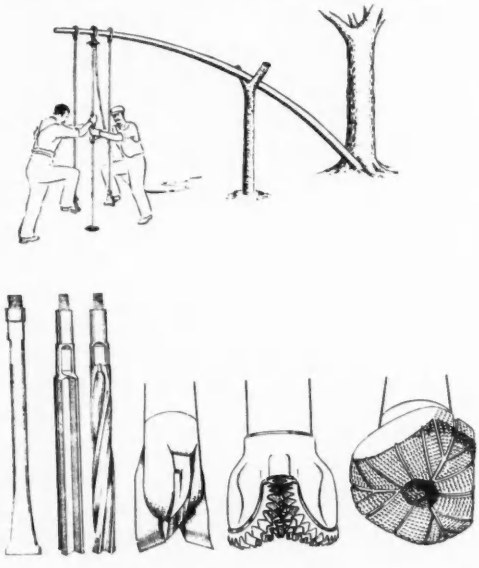
Then one day Drake had an inspiration and ordered all work to cease. " Stop work at once! " he said, "From now on we'll drill *inside a pipe!* " It was at this moment that Drake entered the august Pantheon of true pioneers and earned for himself the distinction of becoming the world's first " oil man ". For it was the use of the pipe for drilling, now called a *casing*, that made the drilling of oil wells really possible.

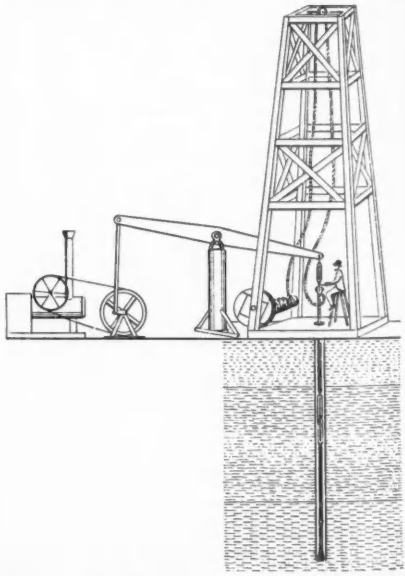
But, even after hitting upon this brilliant idea, success still eluded him; he was practically at the end of his tether and was on the very brink of abandoning the project altogether, when, on Saturday afternoon, August 27, 1859. Uncle Billy and his son withdrew the drill at a depth of 69½ feet, and decided to call it a day. However, on the next day, Sunday, Uncle Billy and his son made a routine visit to the well and, peering into it, noticed a dark thick fluid floating on the water within a few feet of the derrick floor. He lowered a short piece of tin spouting and drew it up filled with oil. Wild with excitement, he mounted his mule and galloped along the main street to Drake shouting all the way " Ile! Ile! Ile! ". Drake had at last struck oil, and the cry of " Oil! " rang round the country as the cry of " Gold! " had done a decade earlier.

One of the first men to take advantage of the tidings of Drake's success was Jonathan Watson, of the timber firm of Brewer, Watson and Co., whose farm had been purchased by Bissell and his associates. Upon hearing the news he mounted his horse and galloped down the valley, spending the day buying up as many leases of farms in the vicinity as he could manage to acquire.

Thus, Drake's well, producing about eight to ten barrels a day, became the cradle of an industry that was to drill nearly 1,800,000 oil wells in the U.S.A. during the next hundred years.

The well at no time produced more than four hundred gallons a day and ceased producing altogether after a few months. But within twelve months of his initial success,





Many early wells were literally 'kicked down' by means of stirrups attached to a pole supporting the drilling bit, as shown in the illustration. Those who could afford steam power often used a steam engine and a rocking beam which raised and dropped the bit. The stirrup-type of drill might deepen the hole by 3 ft per day, as compared with the 200 ft per hour obtainable under suitable conditions with a modern rotary bit. Also shown are (*left to right*) a drilling bit of the type used by Drake, two modern cable-tool bits, and three rotary bits, i.e., a three-bladed drag bit for soft formations, a rock bit for hard formations, and a diamond bit for very hard rock.

some seventy wells had been drilled in the U.S.A. and those which proved successful produced about 500,000 tons of oil. By the end of 1860 there were altogether 74 producing oil wells, and barely five years after Drake's historic strike, no fewer than 543 oil companies were founded in the U.S.A., the narrow strip of sixteen miles along the Oil Creek becoming as if by the wave of a magic wand, one of the busiest spots on the globe.

Petroleum production really got under way when the " flowing well " was drilled along Oil Creek in 1861. The first to startle inhabitants was at the lower end of Oil Creek when, in the spring of that year, a driller not only struck a heavy deposit of oil, but the well started gushing oil at the then astounding rate of 3,000 barrels daily.

Neither Drake, nor the other pioneer drillers, were prepared for the spate of oil which issued from the early wells. Drake himself, in 1859, used wash-tubs, boilers, carboys, odd whiskey barrels, and any other available vessels he could lay his hands on to store his oil. Completely unprepared for this sudden flood of oil, the owners of various wells dug large holes in the ground, cribbed with timber, to store their oil, and very soon these underground tanks covered a good many acres.

The striking of such " flowing wells " in 1861-1862, resulted in a terrific production spurt, jumping from about 1200 barrels a day in 1860 to over 5000 in 1861, so much so that the price of crude oil tumbled from $10 in January 1861 to 50 cents in May and to 10 cents at the end of the year.

The production of petroleum was enormously stepped up after Colonel E. A. L. Roberts, a New York dentist, invented in 1865 his " torpedo ", which basically comprised a cylindrical tube, four feet in length and of suitable bore for the well being drilled. The torpedo, originally filled with gunpowder—later to be replaced by nitroglycerine— was lowered by a wire into the well to any desired depth and was then exploded by the impact of an iron weight or follower allowed to drop down the well. The explosion broke up and dispersed any coagulated matter and, at the same time, opened up fissures in the solid rock. After its first trials at Ladies Well, near Titusville, its success was instantaneous, and hundreds of thousands of these torpedoes were later in use all over the world.

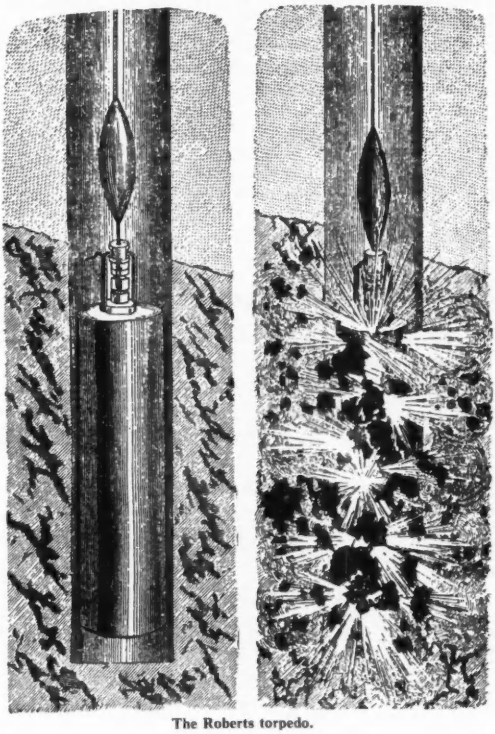
From its very birthpangs, the oil industry exerted an overwhelming influence on the whole fabric of U.S. economy, and, coming as it did in the direst days of the Republic—the Civil War period—oil helped to fill the coffers of the Federal Government in its gravest crisis.

Under the laws of 1862 a special tax on refined crude oil was levied and during the Civil War this yielded $7,000,000 to the U.S. Treasury. When the war was over, oil assisted very substantially in wiping off the huge national debt. Between 1860 and the end of the Civil War in 1865, the amount of petroleum shipped from the U.S.A. rose from nothing to $15,727,881 and ranked sixth in the country's exports after gold, corn, tobacco-leaf, wheat, and wheat-flour.

When President Grant, after the Civil War, visited Titusville on September 14, 1871, on a tour of the oil region, he referred with his customary brevity to the importance of the part petroleum had played in the Civil War. " . . . Your efforts in the discovery and production of petroleum aided materially in supplying the sinews of war as a medium of foreign exchange, taking the place of cotton ".

Simultaneously with the expansion of the American home markets, petroleum was being rapidly introduced into Britain and the rest of Europe. An article in December 1861 in the London *Times* reveals the absorbing interest shown in petroleum in England and the extent to which it had been developing. Captioned " Petroleum, Kerosene, Photogene, or Rock and Well Oil ", this article said, " . . . If the rocks and wells of Pennsylvania, Canada, and other districts continue their exudation at the present rate of supply, the nature of the trade in this oil may even approach that of American cotton . . . For years we have sent coals to America for her gas works, and it would be a singular freak of events if she and Canada should now supply us with a better expedient . . . "

Another interesting contemporary tribute to the great and swift contribution made by petroleum to America's economy during and immediately following the Civil War is given by Sir Samuel Morton Peto, Bart., in his book " The Resources and Prospects of America ", published in 1865, following his visit to America, barely six years after Drake's well. As Sir Samuel Morton said, " This great natural development made its appearance at a period when it was of peculiar value to the United States. At a moment of Civil War, when the balance of trade was against the nation, when there was a heavy drain upon the natural resources of the country, petroleum sprung up,



The Roberts torpedo.

from lands previously considered valueless, in quantities sufficient to make a suitable diversion in the national commerce. Nor was that the only benefit it offered. Whilst it assisted the external commerce, it also stimulated the internal industry of the United States. It gave the railway interests of the country a prospect of large additional profits; it offered employment to capital with

every prospect of abundant returns; and it offered a more than ordinary reward for labour. It is difficult to find a parallel to such a blessing being bestowed upon a nation in the hour of her direst necessity."

Dating a discovery precisely, like fixing the beginning of a revolution, is a perilous historic short-cut. Kier, Bissell and Drake, and other even earlier pioneers, were by no means the " discoverers " of oil, but they were decidedly the pathfinders who blazed the way to its commercial exploitation.

"Oil on the Brain"

The first newspaper in the oil region to carry the story of Drake's strike was the old *Crawford Journal* of Meaville, Pennsylvania. The item, without even a caption, was buried in the inside page, tucked away among trifling local news. On September 13, 1859, the *New York Herald Tribune* also carried an account of Drake's well in a few lines. Because the leading New Haven stockholders in the Seneca Oil Company believed that the oil from Drake's well might be speedily exhausted, they induced the local newspapers to " kill " the story and almost eight weeks elapsed before they made any reference to it.

The news that " Colonel " Drake had struck oil swept across the United States of America and gave rise to a fantastic stampede, strongly reminiscent of the wildest days of the California gold rush of '49. Considering the extremely primitive means of travel and the almost equally primitive methods of communication, the speed with which the news streaked through the country was truly amazing. Nevertheless, a frenzied horde of adventurers of every description at once headed for the oil regions in a mad scramble for quick riches and, almost overnight, the population of sleepy little Titusville increased to 15,000.

Fortunes were made and lost in a trice, owing to the violent fluctuations in supply and demand. Early in 1860, oil sold at $20 a barrel, but by late 1861 it was difficult to dispose of it at 10 cents a barrel. Reckless speculation in oil lands and stocks played havoc with the investments of gullible people, who were often duped into buying stock of fly-by-night companies owning fraudulent, or wholly imaginary leases on oil lands.

The craze to " get into oil ", and the general economic upheaval and excitement created by the oil developments along Oil Creek between 1859 and 1864 are well reflected in several songs and poems which enjoyed wide popularity at that time. All these songs, in keeping with the chaotic business conditions in the oil regions, had flamboyant titles, such as " Famous Oil Firms ", " The American Petroleum Polka ", " Oil-Fever Gallop ", " Pa has Struck Ile " and " Coal Oil Tommy ". One particular favourite was entitled " Oil on the Brain ", dedicated " To the Afflicted ". The first of its many verses ran like this:

The Yankees boast that they make clocks
Which " just beat all creation ",
They never made one could keep time
With our great speculation.
Our stocks, like clocks, go with a spring,
Wind up, run down again;
But all our strikes are sure to cause
" Oil on the Brain ".

Chorus: *Stock's par, stock's up,*
Then on the wane
Everybody's troubled with
" Oil on the Brain ".

There was also a great vogue for topical poems, recited nightly in the many newly sprung-up saloons, one of the specially favoured being " The Bore of the Oil Brigade "—a parody of Tennyson's " Charge of the Light Brigade "—the first verse of which ran as follows:—

Half an inch, half an inch,
Half an inch down
Down to the gates of Hell
Bored the six hundred.
" Downward the Light Brigade,
Bore for the oil, " they said
Into the jaws of Hell
Bored the six hundred.

This rather long poem concluded with these words:

How can their glory fade?
How will their stocks be paid?
All the world wondered.
Look at the holes they made,
And honour the Oil Brigade—
Broken six hundred!

The Wonder of the Nineteenth Century

By June 1860, the year after Drake struck oil, an unpretentious little pamphlet was published under the title " The Wonder of the Nineteenth Century!—Rock Oil in Pennsylvania and Elsewhere ". The author was Thomas A. Gale, who, describing himself as a " Resident of Oil Creek ", claimed to have written the booklet because " many all over the country are desirous of information in relation to Rock Oil—they would know whether it is humbug or not."

After giving a graphic description of the unbridled inrush of speculators and gamblers into Titusville, Gale lists the expenses incurred in drilling a well at the time. Allowing for tools, materials, derrick, pump, steam engine and the actual boring operation, he arrived at a grand total of $1032.50. " To a business which promises to be speedily and largely remunerative," wrote Gale, " men will flock like pigeons to the bait. Such is the Oil Business." And he ruefully adds: " But who has the spare $1000 or $1500 to invest in it? "

Gale's pamphlet represents the first printed account of any size on the earliest oil developments after the completion of Drake's well. After enumerating the various uses of oil and praising its manifold medicinal properties, the most remarkable thing that emerges from this pamphlet is the truly visionary suggestion that petroleum might yet be used to drive boats or locomotives. " What is wanting," said Gale, " is to have the thing tested . . . get up a first-rate apparatus for generating steam from this oil; with the saving of fuel and tonnage claimed, the patent will be worth more than the richest well in Oildom." A truly remarkable prophecy.

It was, however, one thing to find and produce the oil, but it was altogether a different proposition to dispose of it. Drake's early efforts failed on account of the obnoxious odours and poisonous vapours exuding from the petroleum, so much so that when he sent the first hundred barrels to the Seneca Oil Co. in New Haven, the superintendent of the railway company promptly ordered it to be removed because of its offensive smell.

Drake was bitterly disappointed at the slow rate of his sales and remarked wryly to George M. Mowbray, a chemist associated with the wholesale drug firm of Schiefflin & Co., New York, " And now with all the oil obtained—with our entire capital expended—here am I

strained for the necessary means to introduce it, and the whole of the coal-oil market dead against me. I have distributed hundreds of barrels, travelled far and near offering it for one half of the proceeds that may be realized, but have not obtained one cent return."

Mowbray replied confidently: " If I had your oil in New York, I would soon relieve you from this embarrassment."

There and then the two men signed an agreement for the despatch of 300 barrels of oil to New York. But the difficulty was still the repellent smell of the oil; the Seneca Oil Co. was just on the point of taking up refining on a commercial scale when lack of funds and internal dissensions drove the Company into bankruptcy.

It was a Mr. W. H. Abbott, in conjunction with Drake's friend George M. Mowbray, who built the first oil refinery in Titusville in 1861 and by the end of the year fifteen such refineries sprung up in the oil region, all of them with only a small capacity.

Meanwhile, within a few brief months other wells rapidly superseded Drake's output and oil was being produced in earnest. Drake's associates eventually reaped a substantial return on their investment but ironically, the father of the petroleum industry, spent the last twenty years of his life in penury, crippled by arthritis. Towards the end of his days, friends subscribed to a $5000 relief fund and the State of Pennsylvania granted him an annual pension of $1500.

To-day in a little clearing in the forest, about three miles from the centre of the present Titusville, close to the greasy waters of Oil Creek, there stands an impressive 30-ton limestone boulder, bearing on its face a bronze plaque, marking the historic location of Drake's well.

The Age of Kerosene

Before the commercial application of petroleum, glass-chimneyed whale-oil lamps or tallow candles were the prime sources of domestic illumination—when there was any illumination at all. Indeed, most people went to bed with the sun.

With improving living standards, created by the industrial revolution, there developed in the middle of the nineteenth century a fast-growing demand for cheap, plentiful illuminants, fuels, and lubricants.

Candles in those days were unpleasantly smokey and dim; lamps burning whale oil were both expensive and smelly. Hundreds of whaling ships, particularly from New England ports, scoured the oceans from pole to pole in an unceasing hunt for whales. Those were the days of Moby Dick and stirring sea adventures, ranking high in the great treasure house of maritime history. But the supply of whales was running down and there was not enough whale oil to go round.

Substitutes were eagerly being sought and, when the exultant cry of " Oil " went up at Titusville, it literally ushered in the age of kerosene that brought light into millions of homes, and the kerosene lamp became enthroned as the very heart of home life in the then civilized regions of the world.

Very soon after Drake's strike, the *Rayo* lamp made its bow and vastly expanded the consumption of kerosene. With magic speed it began to penetrate every nook and corner of the world. In China it even ousted vegetable-oil illuminants, when the Americans introduced a simple, sturdy and inexpensive little lamp with a tin bowl and small glass chimney. This lamp became a most popular household article throughout China, known under the name of " Mei Foo ", or " beautiful companion ". Under the guidance of J. D. Rockefeller, the Standard Oil Company in America gave away free thousands of these lamps and thereby captured the Far Eastern market.

Kerosene had indeed conquered the world; no other branch of industry or commerce has ever attained so swiftly such enormous proportions and, in doing so, carried more cheap comfort into more homes than almost any discovery in modern times.

Rockefeller Goes into Oil

On November 18, 1859 an inconspicuous item appeared in the *Morning Leader* in Cleveland, stating that the oil springs in Western Pennsylvania continued to attract considerable speculation and that there was an unabating rush to the " oleaginous locations ". This item attracted the attention of a group of Cleveland business men and, in particular, that of John D. Rockefeller, then only twenty years of age, but already a fairly prosperous partner with Maurice B. Clark in a flourishing firm of produce commission merchants. The group of business men eventually decided to send young Rockefeller to Titusville to investigate the much publicized reports of fortunes being made in the oil region, and early in 1860 off went the young man to the by now lawless and vicious oil jungle, carrying in his bag a well-thumbed Bible which he was seen reading daily.

With a perspicacity that was very soon to become a legend in his own lifetime, John D. Rockefeller summed up the prospects of the oil business under three headings, i.e., production, refining and transportation. He at once perceived the hazardous uncertainties latent in the production of oil at that stage, but was impressed by the money-making prospects of refining, though he considered it still as somewhat of a gamble. His advice to his associates was to " wait and see ", as he reasoned that not until a continued and substantial flow of oil appeared to be assured would it be possible to eradicate the wild fluctuation of crude-oil prices and make it safe to step into the refining business.

It took two years before Samuel Andrews, the owner of a small Cleveland oil refinery, finally persuaded Rockefeller in 1863 to enter with his partner Clark into the refinery business.

Samuel Andrews an Englishman of ability and drive, was a self-taught refiner, and one of the first men to realize that kerosene was destined to supplant rock oil as an illuminant. His enthusiasm, coupled with meticulous attention to details and economy, appealed to the business instincts of Rockefeller, who agreed to invest with Clark several thousand dollars, though his own name was kept out of it, the new refinery firm being run as Clark and Andrews. All the same Rockefeller was in oil.

In the opinion of Rockefeller, the paramount requirement was to stabilize oil refining and, above all, to maintain a high and uniform quality of the product sold. Andrews devised methods whereby he obtained larger and larger percentages of a continually improving product from the crude oil.

After a while Rockefeller bought Clark's interests in the business for $75,000. A new partner, Henry M. Flagler, was co-opted and the firm of Rockefeller, Andrews and Flagler went from strength to strength, with Rockefeller becoming the oil industry's dominating influence for the next sixty years. In 1870, Rockefeller and his associates merged their interests in the Standard Oil Company of Ohio, the word " Standard " having been

taken from one of their refineries, and by 1878 secured control of over 90% of U.S. refineries.

Gradually, Rockefeller and his partners conceived the idea of a far-flung combination of commonly owned firms for the refining, piping, storage and distribution of oil in the U.S.A., and by 1881 it expanded so rapidly that it embraced a major segment of the entire American oil industry. In the process, Rockefeller developed a conception that was to culminate in the formation of the gigantic Standard Oil "Trust"—consisting of nine trustees having no legal existence as a corporate body—which was destined to play an important role in modern business life.

For legal technicalities the name of the "Standard Oil Trust" was later changed to the Standard Oil Company of New Jersey, but the very size and power to which the company had so swiftly grown made it vulnerable. Within less than a dozen years, Standard Oil produced 16% of U.S. petroleum, though Rockefeller did not enter the crude-oil-producing field until 1866, Standard Oil practically controlled the country's great pipeline system, it refined 84% of the crude oil produced in the U.S.A., and sold 89% of the country's kerosene.

So vast and powerful did this far-flung network of companies become within a few years that in 1911 a historic U.S. Supreme Court decision ruled that the Standard Oil Company of New Jersey and its thirty-three affiliated companies had violated the Sherman Anti-Trust Law of 1890 and ordered the dissolution of their corporate relationship; these individual subsidiaries thereupon became separate and independent entities.

From Barrels to Pipelines

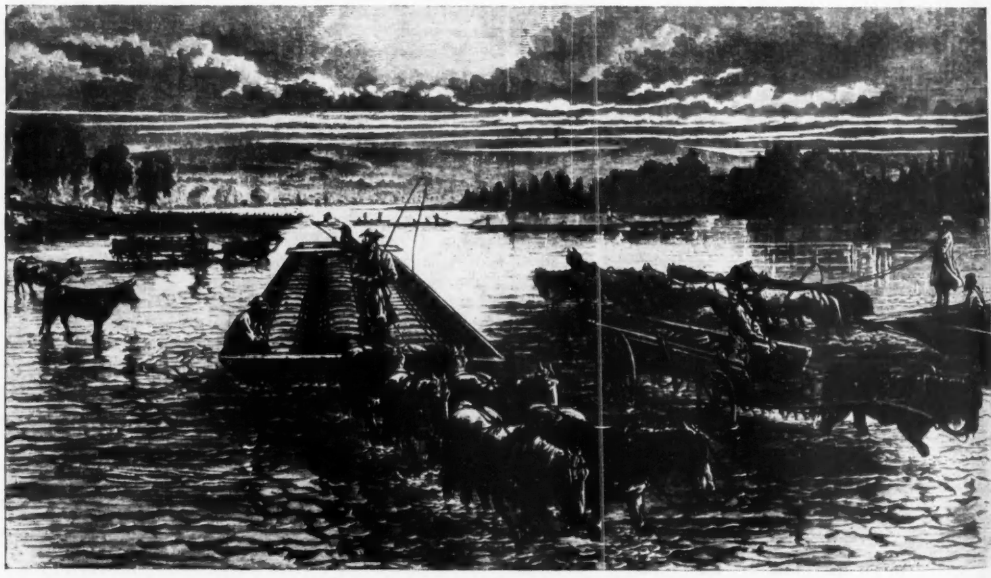
Even when oil has been got out of the ground, it is, more often than not, at a considerable distance from the main centres of consignation and when the modest trickle from Drake's well gave way to a mighty river of liquid gold from many other wells, the all-important consideration was how to transport the petroleum to the legions of potential customers at home and abroad.

The man who has gone down into history as the first known purveyor of oil was Nathaniel Carey, one of the earliest settlers on the Oil Creek, who began collecting oil from the springs and seepages and who, as long ago as 1790, riding on horseback with a small barrel of petroleum hanging from each side of his saddle, introduced petroleum to Pittsburgh. One of the major miracles of the last hundred years has been the swift development from this peddling of a few barrels to the world-wide distribution of millions of tons of oil.

In the teething stage of the industry, crude oil was carried by land and sea in wooden barrels supplied by the customers, and the price of oil was fixed by the barrel, irrespective of its size. However, in 1866 a group of producers in West Virginia issued the following proclamation:—

"We mutually agree that we will sell no crude oil by the barrel or package but by the gallon only. An allowance of two gallons will be made on the gauge of each and every forty gallons in favour of the buyer." Thus did the 42-U.S. gal. barrel emerge as the standard unit for a good many years to come, and it was no uncommon sight to see a mile-long procession of these barrels hauled by teamsters on horse-drawn wagons. Customers feverishly scoured the state for coopers to make 42-gal. barrels with staves of seasoned oak and strong iron hoops. The story goes that a Major Adams, who ran the Clap Farm near Oil City, Pennsylvania, having just sold his first thousand barrels of oil for cash, reached for the wad of money, kicked the nearest barrel upright and counted the $10,000 of oil-smudged bills on the barrel head. This is supposed to have marked the birth of the expression "cash on the barrel".

In April 1860, the steamer *Venango* carried the first load of petroleum to Pittsburgh and within two years there were thirty steamers plying between the newly



Transport of oil across the Allegheny River in 1875.
(*Courtesy of the Illustrated London News*)

established Oil City and Pittsburgh, each with an average capacity of about 800 barrels. These boats made about three trips a week, and, in addition, there was a fleet of about one thousand flat boats used on the Allegheny River, with all the consequent navigational congestion.

The year 1865 marked an important development in the packaging of oil when Charles Pratt, an early pioneer in oil refining, engaged a German inventor, Herman Müller, to improve the package. Müller became the father of the U.S.5-gal or Imperial 4-gal tin, and by 1868 so extensively were these tins being used in preference to the more inflammable wooden barrels, that the firm of Rockefeller, Andrews, and Flagler contracted for 300,000 of these tins, earmarked for shipping oil abroad. Eventually, the manufacture of these tins turned out what is believed to be the first mass-production operation, and one firm stepped up its daily production to the staggering total of 60,000.

The flood of oil brought about swifter and more economic means of transportation. The vast number of barrels made for transportation by countless horse-drawn wagons was followed in 1865 by the introduction of special flat railway cars, each carrying two wooden tanks. These were succeded in 1860 by iron tank cars, and the next stage was the appearance of the pipeline.

The pipeline is, in effect, an American invention, but its basic working prinicples are ancient—thousands of years older than the U.S.A. Indeed, the pipeline, like the wheel, ranks as a fundamental basis of transport. At least six thousand years ago, the Chinese buried pithless bamboo stalks, linked together with clay or pitch, to pipe water by gravity to flow from hillside springs or brooks to homes, villages, or rice fields, and thus ensured an adequate supply of water for one of the world's oldest and greatest industries—agriculture.

The Assyrians, Egyptians, and Romans are known to have used pipes of clay or hollowed rock for water. In the Middles East, a long-distance trans-desert pipeline, made of sewn ox hides, and designed to supply water to the armies of Cambyses, King of Persia, when he invaded Egypt, was laid as long ago as 525 B.C.

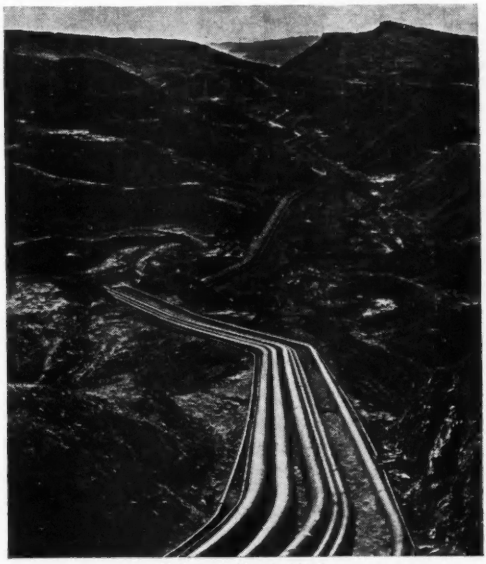
Incidentally, during World War II, Chinese fighting units frequently built bamboo lines to secure for themselves an indispensable water supply. Moreover, this ancient method is still being utilized by the U.S. Department of Agriculture's Tropical Station at Maryagez, Puerto Rico, by importing various types of Asiatic bamboos as pipelines for water transport and drainage.

The earliest known metal pipes were found in the Temple of Abusi in Egypt, and were made of copper some five thousand years ago. In the heyday of the Roman Empire, pipeline building assumed tremendous proportions, and there is evidence to the effect that, by A.D. 97, Rome's aqueducts were carrying the equivalent of 332,000,000 gallons of water daily. Nevertheless the forerunner of the pipeline, in the true sense of the word, was the wooden pipeline constructed in Pennsylvania in 1861, just two years after Drake's well. It was only about six miles in length, but it was a decisive red-letter day in the history of oil transportation.

The idea of running oil through a pipe by using gravity as the motive power was conceived already in 1861 by General G. D. Karns, but, on account of the outbreak of the Civil War, it took him five years to see his dream realized, when in 1865 a pipeline made of iron, about five miles long and two inches in diameter, was completed, delivering, with the aid of a steam pump, some 250 tons of oil daily.

The path of the early pipeline builders was anything but smooth. They met with bitter and fierce opposition from the teamsters carrying petroleum from the wells to the depots, who realizing that their very livelihood was being menaced, resisted by tearing up the pipes, setting fire to the oil storage tanks, and attacking the men engaged in pipe-laying operations. These acts of sabotage did not abate until 1866, when the Governor of the State of Pennsylvania took stern measures to protect the property and men of the pipe-laying companies, ending the days of the teamsters.

The next major step in pipeline development was taken in 1874 when the oilfields of Pennsylvania were linked to Pittsburgh by a 60-mile line, followed in 1876 by a 6-in. 110-mile line carrying oil over the Allegheny Mountains, nearly 2600 ft. high. This pipeline, which truly constitutes one of the outstanding triumphs in the history of the industry, was built by R. D. Benson. In extremely severe winter weather, the pipes for the project had to be hauled on sledges for some three hundred miles over the mountains. In the face of all sorts of difficulties what became known as " Benson's Folly " was eventually crowned by success, when, as president of the pioneering Tide-Water Pipe Co., he turned the valve that started the flow of oil from the Bradford field in Western Pennsylvania to a railhead at Williamsport in the same State.



Modern pipelines in Persia.
(Courtesy of the British Petroleum Company Ltd.)

This achievement signalized the dethronement of the barrel as the principle means of oil transportation. It also gave a tremendous impetus to the subsequent rapid growth of a vast and intricate system of pipelines, prominently inspired by Rockefeller and his associates, establishing itself as the key factor in the expansion of domestic transportation of oil through the country. To-day more than four-fifths of the free world's total, well over 300,000 miles of crude oil, its products, and gas trunk pipelines lie in the U.S.A., in addition to thousands of miles of " gathering " lines.

Gradually the use of cast iron began to be replaced by

steel, and by 1910 the U.S.A. could boast of 40,000 miles of steel arteries. So far, all these lines were carrying crude oil, and it took a further twenty years before this effective method of transport over long distances was applied to refined oil products. The arteries of oil transport are now invariably made of steel, varying in diameter from 6 to 30 in., or even more.

A notable triumph in the history of pipelines during World War II was PLUTO—Pipeline-Under-The-Ocean—which was laid beneath the English Channel to supply petrol to the Allied Forces on the Continent after D-Day. PLUTO consisted of 16 separate lines of two types, the first being a lead pipe, strengthened with steel and fabric wrapping, which could be coiled in the hold of a cable ship and laid in the normal manner. The second type consisted of lengths of mild-steel pipe, welded together and coiled round giant drums, which were towed by tugs when the line was laid.

Quite recently, the launching of a vast Russian pipeline project has been projected in Moscow and is said to comprise the construction of a 2,500 mile major trunk line from the banks of the Volga, to pump oil from the great Volga gushers to East Germany, Poland, Hungary, and Czechoslovakia.

Oil Across the Seas

Long before the modern oil industry came into being, a primitive trade in animal, vegetable and even some mineral oils existed in Burma, the Middle East and elsewhere. Indeed, over two hundred years ago, in 1725, Peter the Great of Russia, issued regulations governing the transportation of oil up the Volga River. This era also saw the early beginnings of sea-going ships carrying oil in bulk, these being Manchuria's Newchwang junks with a carrying capacity of about fifty tons.

The first cargo of oil to cross the Atlantic reached the Port of London in 1861, and was carried by the 224-ton brig *Elizabeth Watts*. The cargo was, of course, in wooden barrels—a highly inflammable cargo, crowded to capacity in a highly inflammable wooden sailing ship. So dangerous was the cargo considered that, after several weeks of complicated loading operations, when the vessel was ready to sail from Philadelphia to London, no crew could be found and men had to be literally shanghaied aboard. Overcoming, however, all such difficulties, shipments of oil grew steadily and, by 1864, some 32,000,000 gallons of oil were transported across the Atlantic.

In 1863, the iron sailing ship *Atlantic* was launched on the Tyne, designed " to carry petroleum in bulk without the aid of casks ". Her holds were divided into compartments by sheet-iron partitions, but there is no record of her having been put into service for the purpose for which she was constructed.

Probably the first bulk-oil carrier was the 800-ton sailing ship *Charles* which traded between the U.S.A. and Europe from 1869 to 1872, and which was fitted with 59 iron tanks of about 15 tons capacity. In later ships, the number of tanks was gradually reduced, and finally this type of oil carrier had only one large tank in each hold. Many ships of this type were built and eventually formed a fleet of famous sailing tankers, comparable with the renowned China clippers, finally disappearing in 1911.

The next step was designing an oil-carrying ship using the skin of the ship itself to serve as the tank walls. In this sense, the first oil-tanker was the 250-ton Swedish built oil-burning *Zoroaster*, delivered in 1878 to the order of Robert and Ludwig Nobel, brothers of Alfred Nobel of explosives fame, for service as an oil carrier from Baku to the Volga delta. Another distinction attached to the *Zoroaster* was that she carried her own pump for loading and discharging the oil.

The year 1886 saw the arrival of the real prototype of the modern tanker, the *Glückauf*, launched by the British shipbuilders, Armstrong Mitchell & Co. (now known as Armstrong Whitworth & Co., Ltd.,), at Newcastle. This ship, specially designed to carry oil in bulk, was 2300 gross tons, 300 ft. in length, and was built for a Heinrich Riedemann of Bremen, who later became a director of the German-American Petroleum Company, now Esso, A.G. The *Glückauf* was equipped with triple-expansion engines, but, to be on the safe side, she also carried sails. The *Glückauf* was the first tanker to have her midship section registered and classified as that of a " Petroleum Steamer ".

Applying improved safety devices in the building of tankers, the strong element of constant fire danger rapidly decreased, and in 1892 the Shell-owned *Murex* made tanker history by being the first ship laden with a cargo of oil to obtain permission to pass through the Suez Canal. The success of the *Murex* constitutes the beginning of the huge Shell tanker fleet of to-day. In 1897, Marcus Samuel (the first Viscount Bearsted) founded the Shell Transport and Trading Co. Ltd. This company concluded a historic alliance in 1907 with the Royal Dutch Petroleum Co.—a combination that is now second only to the Standard Oil Co. of New Jersey amongst the world's seven major oil giants.

When the shipping interests of the Shell Transport and Trading Company and the Royal Dutch Company merged in 1907, the combined fleet, including Dutch vessels, numbered 28 ships, totalling 142,000 tons deadweight. Since then, the fleet has grown steadily, and to-day some 500 ships of owned and chartered tonnage, approximating 8,500,000-tons deadweight, are operated within the Royal Dutch/Shell Group. This is equivalent to about one-sixth of the world's total tanker tonnage.

Gradually coal-burning ships gave way to oil-burning ships and in 1894 the *Baku-Standard* attracted world-wide attention by being the first oil-fired ship to cross the Atlantic, while the first diesel-powered tanker, the *Vulcanus*, made her maiden voyage in 1910 and was the first ocean-going motor ship registered at Lloyds.

Tankers have gone a long way since the *Glückauf* first crossed the Atlantic, and have been continually increasing in size and speed, especially since World War II. While vessels of 30,000 to 40,000-tons, with average speeds of 14 to 16 knots, are the order of the day, larger tankers are being projected and, indeed, the first 100,000-ton tanker made its appearance in 1958. Special ports capable of handling these super-tankers have had to be built, the first one, the largest oil terminal in Europe, having recently been opened at Loch Long, West of Glasgow, in Scotland, close to the Grangemouth refinery.

Before the war, the largest tanker fleet was owned by the United Kingdom and the Commonwealth countries. Losses sustained during the war and the large U.S. maritime programme altered the position, but gradually, with new building, the balance has changed again as shown in Table I, which indicates how tanker deadweight tonnage has grown during the present century.

At the end of 1958, U.K. and Commonwealth tonnage amounted to 16% of the world aggregate, with Liberia having 19%, the U.S.A. 5%, and Norway 15%. It should be remembered, however, that much of the

The 224-ton oil-carrying brig *Elizabeth Watts*.
(Reproduced from a painting by Winston Megoran)

The S.S. *Glückauf*, the first real oil-tanker, built in 1886.

Liberian-registered tonnage is really owned by American interests, who have a great many ships under this and other flags of convenience.

TABLE 1: GROWTH OF TANKER DEADWEIGHT TONNAGE

YEAR	U.K. TONNAGE	WORLD TONNAGE	TOTAL NUMBER OF TANKERS
1900	318,000	531,000	109
1914	1,061,000	1,947,000	300
1919	1,640,000	3,681,000	467
1939	4,384,000	16,600,000	1571
1945	3,931,000	21,668,000	1768
1955	7,281,000	39,015,000	2693
1957	7,824,000	44,377,000	2862
1958	8,363,000	49,582,000	3035

The latest available figures show that about 38% of the world's tanker tonnage is owned by oil companies, 6% by governments for naval purposes, etc., and the balance of 56% by private owners who normally charter their vessels to oil companies, enabling the latter to augment their fleets according to fluctuating requirements, without heavy additional expenditure, and to keep their own ships in continuous operation.

In Britain, the two largest independently owned tanker fleets belong to Hunting & Swan Ltd. and to London and Overseas Freighters Ltd., but the most remarkable achievement in connection with tankers in the past few years has been the fantastic growth of the Niarchos group of tankers. Started in the 1930's by Stavros G. Niarchos, the group now owns the world's largest independent tanker fleet, and it is this group which has recently sponsored the building of the super-tankers, with capacities of over 100,000-tons. These giant super-tankers imply operating economies, as, the larger the ship, the lower is the proportionate cost of transporting each ton of oil she can carry. In this connection, it is interesting to note that, in Great Britain, the Mitchell Engineering Co. has proposed the design of a 100,000-ton submarine oil tanker, capable of travelling underwater at speeds of 50 to 60 knots.

Oil is now the world's most valuable seaborne cargo, and it is estimated that on an average day about 15,000,000 tons of oil and its products, valued at something like £100,000,000 are on the high seas—a very far cry from the door-to-door peddling of petroleum of not so many years ago.

"Dressing" the Crude Oil

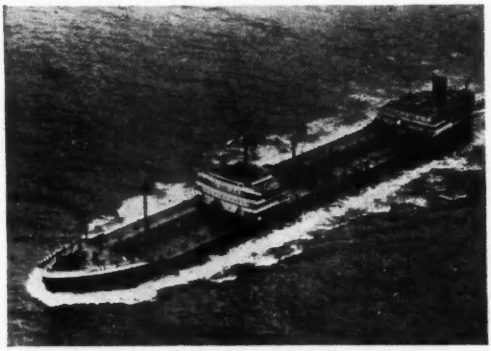
Almost a decade before Drake's well, Kier, of "Rock Oil" fame, had been experimenting with improving his product for lighting purposes, and his keenness to find a good illuminant was shown by the fact that he sent a man over to England in order to learn the methods used for the utilization of shale oil, though the mission failed, as his representative was unable to discover the secrets of the trade.

Undaunted, Kier erected in 1850 a "refinery" in Pittsburgh, comprising a one-barrel still, and thus became America's first oil refiner, naming his product "carbon oil", which after a while began to be used extensively in Pittsburgh for illuminating purposes. He also invented a lamp-burner suitable for any lamp.

Kier's son, William L. Kier, is recorded to have told the story of how the small cast-iron still with which his father had been experimenting was stolen one night by some irate neighbours on Seventh Avenue in Pittsburgh, who were in a state of terror lest the petroleum should explode and possibly cause a disastrous fire in the thickly populated area. Finally, the City Council ordered Kier to remove his "refinery" and he set up a new five-barrel distillation plant outside the city limits.

Generally speaking, crude oil, or petroleum, as it comes out of the ground, is a raw material showing wide variations, and before it can be properly used as a fuel or lubricant, it must be "dressed", i.e., be refined. This process of refining consists of separating its various hydrocarbons by means of fractional distillation into the different products which so widely enter into our industrial and domestic life.

Refining in the early days of the industry was anything but a scientific process. Basically, it applied scientific principles but, as ultimate success depended largely on the



A modern oil-tanker, the 38,000-ton Zaphon, flagship of the Shell tanker fleet.
(Courtesy of the Shell Petroleum Co., Ltd.)

experience and judgment of the man on the job, it was more an art or a skill. All that the early refiners were really aiming at was to separate out the few components of the crude oil that were in great demand, i.e. kerosene, lubricating oil, and asphalt for roadmaking and similar purposes.

The process was carried out in a happy-go-lucky manner, and the purchaser of oil never knew whether it contained the heavier dark oil, making the lamp smoke and smell. Then again, the oil might contain light fractions which easily vaporized and exploded when a match was applied.

Long before petroleum really came into its own and long before man really knew very much about it, efforts were being made by early refiners to devise some method whereby a much greater proportion of the crude oil could be converted into an improved quality lamp oil. As has been the case with many other important inventions and discoveries, the method is said to have been hit upon quite accidentally when, in the early days of refining, a man who was entrusted to look after a small still distilling " lamp-oil ", for some reason or other left the still unattended for about four hours. Upon his return he found that the lamp-oil continued to pass over into the condenser in an unusually large quantity. The proprietor, who happened to have some knowledge of chemistry, promptly adopted it as a method for stepping up the lamp-oil yield, simply by arranging for the heavier vapours of the oil to remain exposed in the still to prolonged heating. This automatically decomposed them partly into lighter oil, representing good quality lamp-oil, the ratio of which was thus raised by 20%. This process, as distinct from distillation, was in later years destined to revolutionize the oil industry by the introduction of what was to be called the " cracking " system.

The first *real* refinery to be built after Drake's strike was that of William H. Abbott, who, in 1861, in conjunction with George M. Mowbray, a chemist, built at Titusville, the forerunner of America's great refineries. An important milestone along the road of more scientific oil refining was the process developed by Samuel Andrews, for cleansing petroleum by the use of sulphuric acid.

Even the modest quantity of oil produced by Drake's well was largely wasted, because, after extracting its kerosene content, the remainder was regarded as utterly valueless. In fact, right up to the early part of this century, what we now know as petrol or gasoline was considered useless, and countless millions of gallons were wasted by piping it off to a safe place and burning it. Little did those who celebrated Drake's success realize that it was the products they were wasting, and not the kerosene, which were destined to contribute most to the phenomenal growth of the oil industry as we know it to-day, though it is true that the pendulum has swung back to some extent with the development of the jet engine.

A new chapter in oil refining was opened up in 1907 with the introduction of a process by L. Edeleanu, of Rumania. The process, named after him, ensured that the kerosene was separated into good and inferior constituents. The Edeleanu process is still being used to treat similarly gasoline, gas oil, and lubricating oil.

With the real emergence of the internal combustion engine around 1900 there ensued a phenomenal demand for gasoline and, in order to cope with it, a more efficacious method had to be evolved to ensure a plentiful supply. Thus developed the process of cracking a method of decomposing heavy oil into a lighter oil by the application of considerable heat. At quite an early stage in the history of the industry, it had been found that, by subjecting the crude oil to intense heat, the heavier hydrocarbons decomposed, or " cracked ", producing a light product (gasoline) at the expense of the heavier product (kerosene).

Instead of obtaining 20% of gasolene from the old process of distillation from a given quantity of crude oil, the yield of gasoline more than doubled by applying the cracking process. In fact, without the cracking process, twice the volume of crude petroleum would have to be produced annually in order to cope with present-day petrol requirements.

Thermal cracking, as the original process was named, was first applied on a substantial scale by Dr. William Burton in 1913 in the Whitney refinery of the Standard Oil Company of Indiana, near Chicago. Burton, who is claimed to have been the first chemist specially trained for entry into the petroleum industry, was really following in the footsteps of John Dalton, often described as the father of the atomic theory, who had produced ethylene by cracking oil with an electric arc as early as 1809.

A careful study of cracked gasoline eventually disclosed the behaviour of different types of fuel, revealing the fact that cracked gasolines give smoother engine performances, largely eliminating knocking and pinking, thus immeasurably facilitating the design of engines with higher compression ratios, yielding more power for their size.

By the early 1930's the Frenchman Eugene Houdry had been experimenting with the catalytic cracking of oil. This process does not necessarily subject the oil to high heat pressure, but, instead, it employs a catalyst. Since its introduction in 1937, catalytic cracking has become of supreme importance, and during World War II it provided the direly needed high-octane petrols as base stocks for diverse aviation-fuel blends.

Within a very few years the far-reaching results of modern refining have ousted kerosene from its former eminence as a primary source for lighting. Moreover, with the arrival of a variety of new fuels, vast new engineering vistas have opened up.

Until the steam locomotive became a reliable means of transport early in the nineteenth century, there was nothing to rival a horse. But steam propulsion required a boiler full of water and a tender full of coal; an engine that could develop power internally and use a conveniently portable fuel had yet to come. And when the internal combustion engine arrived and brought in its wake the diesel engine, the car, and the aeroplane, the age of steam was over.

The Importance of Lubricants

Before the world could take to the road and before man could conquer the highways in the sky, it fell to the great evolution of lubrication to make one of the indispensable contributions to the development of modern machinery on which transport and industry depend.

It is, of course, a truism that, where there are machines, there is an inexorable need for lubricants, and mankind made use of lubricants many centuries before the science of lubrication was understood. Traces of lubricants have been found on the wheels of a chariot dating back to 1400 B.C., and chemical analysis found this to be an animal fat—for thousands of years a common type of lubricant.

In the very early stages of the machine age, man had

to rely for lubricants on animal fat, tallow, lard, whale oil, palm oil, or olive oil. The most primitive methods of lubrication appear to have sufficed, until the advent of the industrial revolution heralded the introduction of power-driven machinery. Even so, for a considerable time, these " new-fangled " machines received haphazard and rough treatment. The first stationary steam engines of the eighteenth century were lubricated with melted tallow or vegetable oil, poured on spasmodically, and the only half-hearted attempt at continuous lubrication was to pack large open bearings with sides of pork. Even in 1886, blocks of ice were placed in a basket over the bearings of a lighting plant at the Fifth Avenue Hotel, New York, to keep the bearings cool.

A prominent place is held in the ranks of lubrication pioneers by Dr. James Young, the Glasgow chemist, who in 1847, produced a number of useful products when he found oil trickling from coal-bearing strata. The chief of these products was paraffin-wax, produced first from Derbyshire Boghead Coal, and subsequently, when this became scarce, from Scottish oil shale. Dr. Young (" Paraffin Young " as he came to be called) made a useful contribution to the development of lubrication by producing a variety of lubricants on a small scale.

Around 1880, methods of lubrication underwent a revolution, particularly in connection with the application of the oil bath that afforded continuous lubrication to bearings and reduced friction present to about one tenth of what it was in the days of hand lubrication, which alternately flooded the moving parts with oil and then left them dry.

The true birth of the petroleum lubricating industry can be ascribed to the efforts of Hiram B. Everest, a grocer of Rochester, N.Y., who became interested in, and eventually backed financially, a process evolved by Matthew P. Ewing for obtaining an increased yield of kerosene from crude oil by vacuum distillation. It was hoped that this process would enable the entire crude-oil content to be changed to kerosene, but it soon became evident that there was always a residual product which did not react to distillation. Everest at once began to consider the commercial possibilities of the residue itself, and soon *Ewing's Patent Vacuum Oil* was enjoying considerable favour as being superior to animal

A study in contrasts, showing (*right*) a typical 1864 refinery capable of processing from 700 to 14,000 tons of crude oil per year, as compared (*below*) with a view of part of the modern Esso refinery at Fawley, which treats over 10,000,000 tons of crude oil per year.
(Photograph of the early refinery by courtesy of the Drake Museum, Titusville, Pa.)

and fish oils—at least for the treatment of leather.

Improvements in distillation followed, and new uses were found by Everest for the material. Thus was born in 1866 the Vacuum Oil Company, which was soon marketing harness oil, steam cylinder lubricating oil, and general lubrication oil, in addition to kerosene. From the outset, Everest was conscious of the possibilities of lubricating oil and, unlike other expanding oil companies, Vacuum Oil developed mainly for the production of lubricating oil, with kerosene as a by-product, and, in so doing, helped to give birth to a brand-new branch of the oil industry. In 1879, the Vacuum Oil Company merged with Standard Oil, forming what is now known in the U.S.A. as Socony-Vacuum Oil Inc., and in Britain as the Mobil Oil Co. Ltd.

The first Vacuum Oil refinery.
(Courtesy of the Mobiloil Company Ltd.)

Although lubricants represent only a fraction of all the refined products obtained from petroleum, oil derived from this source accounts for about 90% of all lubricants, ranging from extremely thin fluids, suitable for very delicate mechanisms, to thick oils and semi-solid materials. As mineral oils can easily be blended together, an almost infinite number of lubricants of different viscosity can be produced, with or without additives for special applications.

Britain has played an important part in the advancement of the commercial use of additives. Thus, C. C. Wakefield Ltd. perfected in 1935 two new compounds (oleates of tin and chromium) for imparting remarkable anti-oxidation and anti-corrosion properties, as well as for giving the oil certain detergent-dispersant qualities. This was the first commercial use of additives in a motor oil and anticipated by ten years a similar trend in the U.S.A.

Lubrication engineering to-day is a highly complex and specialized science, with the result that a large number of lubricants have gradually been evolved to meet the more complicated and exacting demands of the modern machine age. Indeed, the machine age could not have come about without the necessary lubricants produced from petroleum.

The World takes to the Road

Just about a decade before World War I, striking events were taking place, affecting fundamentally the entire fabric of domestic and communal life throughout the world. Motion pictures had just arrived, and radio broadcasting, though still in its embryonic form, was on the way; however, perhaps the most powerful influence in the shaping of twentieth-century life, first in America, and gradually all over the globe, was the arrival of the motor car. To begin with it was, of course, the toy of the very rich, but before the lapse of many years it established itself as the exact opposite—a cheap and reliable means of transport for the masses.

Self-propelled vehicles date back to the middle of the eighteenth century, but credit for the presentation of the first " road wagon ", propelled by its own engine, is usually accorded to the Frenchman, Nicolas Cugnot, who about 1769 built a three-wheeled carriage, equipped with a cumbersome and complicated steam power plant on the single front wheel. This contraption is claimed to have run at 2½ mph, but it had to stop after almost every 20 yds to build up steam pressure. Even before that, Cugnot had devised two steam-driven carriages for hauling artillery.

It is interesting to note that, between 1824 and 1836, an appreciable number of steam coaches, devised independently by Sir Goldsworth Gurney and by Walter Hancock, were operating successfully over the roads in various parts of Britain, some of these vehicles attaining a speed of 20 mph. However, they were eventually driven off the roads, owing to opposition from railway and stage-coach interests, by means of exorbitant tolls levied against them and by legislation culminating in the iniquitous " Red Flag Law ", which required a man to precede any such mechanical vehicle with a red flag by day and a lantern at night.

Contrary to popular belief, the internal combustion engine is not entirely of recent origin, the first successful engine of this type having been patented in 1860. This was followed by the epochal engine of Dr. N. A. Otto, which was to prove the basis upon which most modern engines operate. In 1890 H. Akroyd Stuart, designed in England an internal-combustion engine running on oil which used the " solid injection " system of fuel supply for driving stationary plant—a system practically in universal use to-day. The time had come when petroleum spirit came into use and a portable form of power became available for transport purposes.

There was, however, still much to be done before the new oil engine could be termed a true compression-ignition engine and it remained for Dr. Rudolf Diesel, who had worked at one time under the great Nicolaus August Otto, to produce the engine with which his name is indissolubly associated. He patented his engine in 1894, but it was only in 1897 when Diesel saw his engine run under its own power for the first time, in the following year he exhibited it at the great Munich Exhibition, and its patents and sole manufacturing rights for the U.S.A. and Canada were bought from him then and there for 1,000,000 gold marks by Adolphus Busch, a brewer of St. Louis, Missouri, who subsequently formed the American Diesel Engine Company. The first American-built diesel engine was put to work in September 1898 to generate current in the Anheuser-Busch brewery, and from this installation stemmed with remarkable rapidity the use of diesel-engines in America.

The first diesel engine operating in Britain was built in 1897 by Mirrless, Watson and Yarian Ltd., of Glasgow, a firm now known as Mirrless, Bickerton & Day Ltd.

Meanwhile, the era of gasoline had dawned and with it there arrived the motor car. The motor car is really not the product of a single inventor, but the most dramatic step towards motoring, as we know it to-day, was

when Gottlieb Daimler of Germany produced his first car in 1885. Ten years earlier, the Austrian, Siegfried Markus, built a four-wheeled car propelled by an internal combustion engine, and soon after Karl Benz of Germany constructed his tricycle fitted with a small benzene-driven engine. Of the many car pioneers special credit must be given to the ingenious German designer Krebs for the production of the Panhard car in 1894, which was the first gasoline-powered automobile to incorporate all the salient features of modern cars, including a vertical engine under a bonnet at the front, a fairly modern looking chassis, a sliding gear transmission, a clutch, brake-pedals and a foot accelerator.

In America the first gasoline car was built in 1892 by Frank and Charles Duryea, of Springfield, Massachusetts, its main feature being a one cylinder gasoline engine attached to an ordinary buggy. However, it attracted very little attention as a possible means of transport until it won a $6000 race, sponsored by the Chicago *Times-Herald* in the same year. This was America's first car race, from Jackson Park, Chicago, to Evanston and back, a distance of fifty-two miles. Of the entrants only two were able to finish the course, Duryea's horseless buggy, and an imported German Benz car, the winner streaking home at a speed of no less than 7½ mph.

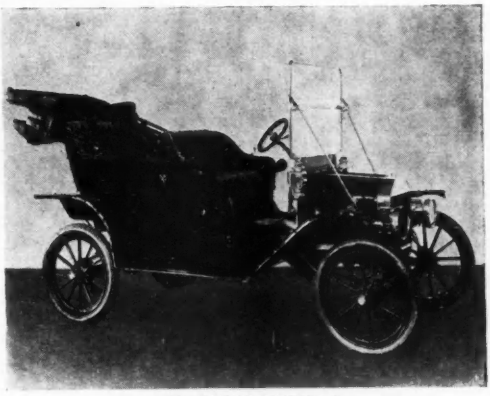
In connection with the Chicago-Evanston race, a price of $500 was also offered for the best generic term to describe these new-fangled contraptions. The Duryea brothers called their entry the *buggy-aut*, and other names included *quadricycle* and *petrocar*, but the winning entry was *motocycle*. Two unsuccessful entries, not even in the running, were—*motocar* and *automobile!*

Charles and Frank Duryea organized in 1895 the first motor-car factory in the United States under the name of The Duryea Motor Wagon Co. of Springfield, Mass. By 1901 Ransom Eli Olds launched the quantity production of his famous *Oldsmobile*, of which he turned out 421 in twelve months and no fewer than 6500 in the year 1905. Mass production began in earnest when, in 1908, Henry Ford presented the world with his immortal "Model T", destined to win international renown as "Tin Lizzie". Ford produced a car for the multitude and through it gave a decisive spurt to the gasoline age. Remarkably enough the famous "999" built by Ford in 1902 was driven by Barney Oldfield in 1904 at a speed of 91.4 mph.

From the modest total of four cars running in 1896 throughout the length and breadth of the United States of America, (a Ford, a Duryea, a Haynes, and a Benz), the number of cars by 1911 soared to 600,000 and when, in 1924, Henry Ford, by stripping his Model T of all unessential gadgets and refinements, reduced its price from its original $1000 to $290, he built no less than 15,000,000 of these cars and led the world well and truly into the motor-car age, with the number of cars now in use in the U.S.A. alone well within sight of the 60,000,000 mark.

In Great Britain, less than twenty people could boast of a car in 1897—all of them dyed-in-the-wool enthusiasts, deeply resented and detested by the rest of the population. It took years before the Red Flag Law, already mentioned, was repealed (November 14, 1896), an event which is celebrated annually ever since as Emancipation Day by the Veteran Cars run from London to Brighton. By 1913, there were over 100,000 cars registered in the U.K., the number of licensed vehicles (excluding motor-cycles) now approaching 5,000,000.

Milestones in the development of the automobile include Dunlop's pneumatic tyre in 1889, and the Rolls Royce in 1904, which did much to improve the reliability of motor cars and, even then, became synonymous with perfection. In 1905, the hire-purchase system of buying cars was introduced into the U.S.A., while 1907 saw the first appearance, also in America, of a petrol service pump installed in Seattle by Standard Oil; in 1912, the first successful electric self-starter was introduced and did much to attract the interest of potential women drivers, and in 1913 the first drive-in service stations were inaugurated in the U.S.A., coupled with the free distribution of road-maps—all powerful recruiting stimulants for buyers of new cars.



The 1908 Model 'T' Ford.

A recent authoritative U.S. survey on the number of internal-combustion engines on the road and land everywhere throughout the world shows that the global aggregate is now approaching the 150,000,000 mark. In January 1959, the number of passenger cars in use throughout the world was 86,000,000, of commercial vehicles 25,500,000, of motor cycles about 20,000,000 and of farm tractors more than 10,500,000.

Even in the early 1920's, motor manufacturers realized that the steadily increasing power of engines necessitated a fuel that would reduce, or altogether eliminate, detonation, knock, or pinking—the bane of early motorists. Although the effects of knock were first noted in 1882, it was neglected until World War I, when the demand for better engines, particularly for aircraft, forced the problem to the forefront. It was a General Motors research team, headed by Thomas Midgley Jr., which gave the development of petrol engines a dramatic impetus when, in 1921, they discovered the anti-knock properties of tetraethyl-lead, but it was not until 1924 that its commercial application was launched by the Ethyl Gasoline Corporation, jointly set up by General Motors and the Standard Oil Company of New Jersey.

Highways in the Sky

In 1851, the French engineer, Henri Giffard, developed the first aeronautical engine, a steam engine which with its boiler weighed 351 lb and developed 3 hp. This engine made possible the first controlled navigation of the air in September 1852, when Giffard piloted his airship from Paris to Trappes. However, shortly after the inauguration of the modern oil industry, and the successful efforts of pioneers like Daimler, Benz, Panhard, Levassor, and other designers of motor cars, it was not long

before the type of internal combustion engine used in cars was being experimentally fitted to light wooden frames, shaped like a box-kite.

The next step was the design of internal combustion engines specifically intended for aircraft, and, of the many early aero-engine designs the most noteworthy was that of Charles M. Manly, who in 1902 devised the radial type of engine, which in later years became accepted as a popular type of engine for aircraft propulsion. At its first trial, the engine failed, due to catapult-gear trouble, but functioned successfully some years later without any modifications.

For some time, two brothers, Orville and Wilbur Wright, had been experimenting with various engines, and Orville Wright is recorded to have said: " Give me a motor that is light enough and powerful enough and with it I will fly a kitchen table." It fell to the Wright brothers to evolve the first petrol engine to be used in a successful power-driven aeroplane, theirs being the first heavier-than-air machine to become airborne. This epic event took place on December 18, 1903, at Kitty Hawk, North Carolina, and was witnessed by only a few people.

The toss of a coin decided which of the two brothers should fly it first. Wilbur won and made the first flight on record, lasting exactly twelve seconds and covering a distance of 120 ft. at a height of 10 ft., with the machine under control, maintaining its height and landing safely. At the fourth trial the machine flew for fifty-nine seconds, covering a distance of 852 ft.

Rapid progress followed. The Wright brothers and other enthusiasts soon built better and better machines and nowhere was there greater interest evinced than in France. It is, indeed, to the eternal credit of the Frenchman Louis Blériot that, by his Channel crossing from Calais to Dover, on July 25, 1909, he made perhaps the most memorable of all flights.

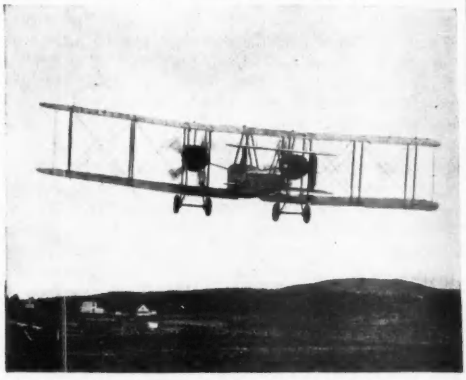
The 1914–18 war gave a tremendous upswing to the development of the aeroplane, and soon the knowledge thus gained was put to civilian use. By August 1919, the first British commercial air company, Aircraft Transport and Travel Ltd., started a regular daily passenger service from Hounslow (then the airport of London) to Le Bourget. In the same year Alcock and Brown flew the Atlantic from west to east in a Vickers " Vimy ", while the airship R.34 made the first England-America-England round trip. The subsequent disaster to the R.101, on her maiden flight to India in 1929, curtailed airship development in Britain. In 1920, the Dutch K.L.M. became the worlds' first major airline to operate internationally.

Another outstanding aviation event of that period was the solo non-stop crossing of the Atlantic by Charles Lindbergh in 1927, followed by the exploits of such distinguished aeronautical pioneers as Amy Johnson, the first woman to fly from England to Australia (1930), Jim Mollison's first solo Atlantic flight East to West (1931), I. M. Codos and M. Rossi's longest non-stop flight of 5600 miles from New York to Rayak in Syria in 1933, and Jean Batten's achievement of the double honour of being the first woman to fly solo from England to Australia and back in 1935.

During the testing days of World War II, aircraft played a decisive part in the struggle both in defence and attack. Indeed, it was Germany's much vaunted air power that induced the Nazi régime to launch their " total war " in 1939, and after the Battle of Britain, it was the Allies' preponderating air might, coupled with Germany's ultimate lack of oil, that brought their dreaded war machine to its ignoble end.

Most important of all the wartime aeronautical developments was the first successful flight of the famous Gloster E/28/29 with a Whittle jet engine on May 14, 1941. This flight ushered in the age of jet propulsion, linked for ever with the name of Air Commodore Sir Frank Whittle, who designed the jet engine, in the evolution of which oil technologists played a prominent role. Of particular importance was their design of a combustion chamber using atomized spray injection for Whittle's epoch-making engine.

The first major application of jet propulsion, however, was made by the Germans, first in connection with the V.1 " flying bomb " and subsequently with their V.2 rocket missile. When the war was over, the way was clear for the future that was to produce the Vickers Viscount, the De Havilland Comet, the Boeing 707, the Soviet TU 114, and supersonic flying.



The take-off from St. John's, Newfoundland, of the Vickers "Vimy" on June 14, 1919, by Alcock and Brown.
(Courtesy of Vickers-Armstrongs, Ltd.)

The latest British contribution to aviation is the Saunders-Roe *Hovercraft*—the " flying saucer "—which recently crossed the Channel from Calais to Dover, this craft being designed to travel about 18in. above the surface of water or flat ground on a cushion of air. Saunders-Roe foresee a 400-ton *Hovercraft* cruising at 100 knots at a height of between 3 and 8 ft. using only a fraction of the power required by an aircraft of similar size.

Unquestionably, the aeroplane is one of the most important inventions of the twentieth century. It has brought about a complete transformation of warfare, and its peace-time uses have already wielded incalculable influence on the whole structure of civilized life.

Magic in Molecules

Scientists on both sides of the Atlantic were greatly impressed around 1926 with a process called " hydrogenation ", embarked upon on a large scale by the I.G. Farbenindustrie (German Dye Trust) research centre at Ludwigshaven, for making oil from coal, Germany having very much more coal than oil.

What interested Anglo-American technologists was not so much the utilization of coal but rather the wide range and variety of changes the process seemed able to induce in hydrocarbons. The basis of the German process was the application of catalysts, promising a vista of possibilities of truly revolutionary dimensions. The inventor of this oil-from-coal process was Dr. F. K. R. Bergius

and it won him, jointly with Carl Bosch, the 1931 Nobel Prize for chemistry. The Bergius process for converting coal into oil, petrol, and lubricants, and for making "ersatz" food and fodder proved of very considerable value in Germany's war effort during 1939-1945.

American interests acquired the foreign rights of the process and, by 1929, petroleum technologists went to work in the great new research laboratories established by the leading American and British oil concerns and before the outbreak of World War II obtained important results, destined to play a role of vital importance during the war itself, including the development of 100-octane aviation fuel.

Research activities in the years immediately after the war resulted in the rise and spectacular expansion of what has now become known as the Petroleum Chemicals Industry for the manufacture of diverse materials made from petroleum fractions, refinery by-products, and natural gas. So extensive has this development become that a stage has now been reached when petroleum has ceased to have "by-products", and, taking a leaf out from the book of the meat-packing industry which utilizes everything of the pig except its grunt, it has become true of oil that it utilizes everything in crude oil except its smell. And even that has its uses as a means of detection of leaks in pipeline systems.

The march of petrochemicals has been particularly spectacular in the U.S.A., where synthetic chemicals from petroleum, it is estimated, now represent 25% of all chemical production, with the proportion going up year after year; for some chemicals the proportion has already reached 60%. There is a similar trend in other countries, and Britain can boast of having the second largest petrochemical industry in the world—all of it based on imported oil.

Many of the chemicals used as raw materials for the manufacture of plastics and synthetic fibres are now derived from petroleum. Petroleum-based plastics reach the consumer in a wide variety of forms, ranging from transparent wrapping-films to extruded wire-coverings and innumerable kinds of moulded goods. Indeed, quite apart from the major uses made of petroleum, there are hundreds of products made from it which now enter our daily lives in a great many wholly unsuspected directions and, according to recent authentic American estimates, the petroleum industry is now responsible for the production of some three thousand products.

In addition to a great variety of solvents made from oil for industrial purposes too numerous to list, there has been the phenomenal emergence of "soapless soaps", with the capturing of the world market by a whole range of synthetic detergents.

Large quantities of petroleum-based synthetic rubber were produced in the U.S.A. and Canada during the war, and proved particularly suitable for inner tubes for tyres, and in some respects even superior to natural rubber. In recent years, the great modern plants in Britain, Germany, and Italy have greatly added to European synthetic-rubber production.

Increasing quantities of agricultural chemicals are being made from petroleum, including soil fumigants for destroying eel-worms and similar pests, selective weed-killers, and fertilizers. In addition, a wide variety of insecticides, moth-proofing agents, etc. is also made from petroleum.

The extent to which the production of glycerine from petroleum has advanced is amply indicated by the fact that the output of two firms in the U.S.A. accounts for 40% of her entire glycerine production.

In the very nature of things, the U.S.A. was the birthplace of the petrochemical industry and is to-day the foremost producer of petrochemicals, accounting for over 85% of the world's output of these products. Nevertheless, during the past ten to fifteen years, Britain, without enjoying the advantage of a highly developed oil-producing industry and an abundance of natural gas, has successfully embarked upon the large-scale manufacture of petroleum chemicals, under the leadership of the major oil and chemical companies.

With considerable justification, a barrel of oil is now looked upon by petroleum technologists as an almost bottomless storehouse of priceless treasures, and they are fully convinced that, such is the magic in molecules, that the three thousand products already emanating from it are merely the beginning.

The Unceasing Quest for Oil

It was during World War I that the importance of oil was dramatically highlighted. Its significance was succinctly summarized by the French war leader, Premier Georges Clemenceau, when he said: "A drop of oil is worth a drop of blood."

In 1909, the Royal Navy had already introduced oil-fired destroyers, the man mainly responsible for this crucial innovation being Mr. Winston S. Churchill, then First Lord of the Admiralty, who, with characteristic foresight and determination, backed the views of Admiral Lord Fisher, for long a dogged advocate of the use of oil for naval speed, for which his critics dubbed him "the oil maniac".

The Royal Navy had, in fact, been exploring the possibility of burning oil in some of its vessels as far back as 1866. On the other hand, it is amusing to recall in this connection that similar experiments by the U.S. Navy were considered totally unsatisfactory, and B. F. Isherwood, the Chief of the U.S. Bureau of Steam Engineering gave, in 1867, this summary to his report to the Secretary of the Navy: "From these considerations it appears that the use of petroleum as a fuel for steamers is hopeless; convenience is against it, comfort is against it, health is against it, and safety is against it. Opposed to these, the advantages of the probably not very important reduction in bulk and weight, with their attending economies, cannot prevail."

Ultimately, in Britain, the supporters of oil won the day and, in May 1914, with the active support of Lloyd George, Churchill induced the Government to invest £2,001,000 in the acquisition of a fraction over 50% of the shares in the Anglo-Persian Oil Company, in order to ensure an adequate flow of oil for Britain's ships. The great Abadan refinery, commissioned in 1913 in Persia, was just completed when war broke out in 1914. It was due to this providential and timely provision that, in the classic dictum of Curzon, "the Allies floated to victory on a sea of oil".

In World War II, oil played an even more decisive part. It was mainly responsible for winning the equally vital battle of the home front. It kept the railways rolling, moving as they did the biggest loads in their history, it ensured the uninterrupted working of farm tractors and other agricultural machinery, it heated the factories and homes throughout these islands, and enabled workers to get to their jobs.

The very importance attained by oil in war has,

in turn, altogether altered the economic structure and potentiality of countries by their dependence on oil, which they either possess in abundance or are forced to rely on another country for its supply. Oil has thus become a vital pawn in international rivalry, and has given rise to an unceasing global search for oil ever since the Pennsylvania oil strikes in 1859. However, the speculative and haphazard " wild-cat " type of drilling for oil has long since vanished, and to-day in exploring untapped territories, highly scientific methods are now used.

All kinds of fanciful methods were used by early oil explorers for locating a suitable place to drill, including the witch-hazel divining rod. Other methods, relied on an even less substantial basis, including interpretation of dreams and even a keen sense of smell.

Early drillers found that the big wells and oil pools appeared to line up in " trends ", this " trendology " technique being first expounded as long ago as 1874 by Cyrus D. Angell, a merchant who later became an oil prospector. After drilling several wells, Angell came to the conclusion that petroleum existed in " belts ".

A distinguished geologist, Walter E. Pratt, put forward the theory that intercontinental depressions marked by landlocked seas are the world's principal oil regions. In the western hemisphere, the Gulf of Mexico and the Caribbean Sea lie between the continents of North and South America. This area includes such important oil producers as Venezuela, Trinidad, Colombia, Mexico, and in the United States the State of Louisiana, together with part of Texas. Similarly, another great basin is the Mediterranean region of the old-world, low-lying lands surrounding the Persian Gulf, the Black, Caspian and Red Seas, and the eastern end of the Mediterranean situated between the continents of Africa, Europe and Asia. This great oil-bearing area holds the fabulous fields of Persia, the U.S.S.R., Iraq, and Arabia.

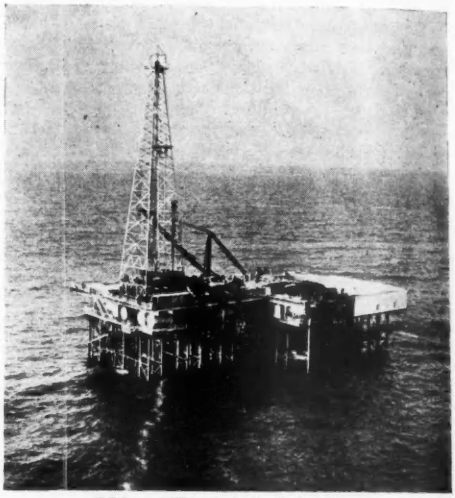
The three main methods applied nowadays to oil exploration are the seismic, the gravimetric, and the magnetic techniques. Most widely used and effective is the seismic method of studying underground rock formations with a view to finding oil, based on the fact that earthquake waves travel rapidly through hard formations and less rapidly through soft, and are refracted by certain types of rock. The main feature of the method is to create artificial " earthquakes ", and to record the time taken for the waves to be reflected back.

The gravimetric method, developed since 1920, depends on measurements made by sensitive instruments, which record with extreme accuracy the minute variations in the pull of gravity at particular points of the earth. Once those are plotted, it is possible to deduce fairly accurately the presence of different rock masses at varying depths, and, if conditions are favourable, the existence of geological structures likely to contain oil. Its main attraction is that this method permits rapid conclusions to be made at comparatively moderate cost.

The magnetic system of exploration relies on the magnetometer for measuring the intensity and direction of the earth's magnetic field. From local variations in the field, the structure of rocks with varying magnetic properties can be inferred. In recent years, airborne magnometric sweeps have proved quite efficacious, with the added advantage of saving time and cost. Research scientists of the Gulf Oil Corporation of Pittsburgh, Pa., developed the flying magnetometer, and its counterpart became famous during the last war as the airborne submarine detector.

The advance in techniques of oil exploration is in itself a fascinating chapter in the kaleidoscopic story of the oil industry. The geologist in search of oil is now aided by the use of the aeroplane, the helicopter, a number of new geophysical techniques, and various electronic devices.

Drilling for oil is, of course, a totally different matter from the primitive days of Drake. The twilight of percussion drilling came in 1901 when Captain Anthony F. Lucas used for the first time on a large scale the much more powerful method of rotary drilling for his famous well at Spindletop, Texas, the first gusher with an estimated daily output of 100,000 barrels, heralding the beginning of the great Texas oil boom and the birth of the group of Gulf Oil companies. Actually, rotary drilling was introduced in 1895, when M. C. and C. E. Baker applied it for commercial production while drilling water wells at Corsicana, Texas.



Offshore drilling rig in the Gulf of Mexico.
(*Courtesy of the Standard Oil Company (New Jersey)*)

The truly great drilling achievements occurred only during the past quarter of a century or so. It was seventy-two years after Drake's 69½-ft well before a depth of 10,000 ft was reached in 1931; by 1938 a depth of 25,340 ft was reached.

In the industry's ever-widening search for new oil and gas sources, petroleum activities have moved from land to inland marshes and lakes and even to the open sea - challenging Neptune in his own domain. Since the end of the last war, some 2700 wells have been drilled offshore in open waters, with over 2400 of these since 1954, most of them off the Texas coast, in the Mexican Gulf (between Trinidad and Venezuela), the Persian Gulf, and the East Indies. In the Gulf of Mexico, for example, wells have been drilled forty miles from the shore over 100 ft below the surface of the sea.

Mobile drilling barges are now being increasingly used for underwater oil drilling, and monster mobile drilling platforms have been introduced as the industry's task force in these operations. Very recently the first mobile oil-drilling petroleum platform to be built in the United Kingdom, the *Orient Explorer*, fitted with a helicopter landing stage and constructed to withstand winds of 100 mph, was towed some 9000 miles from Southampton to Borneo for exploratory drilling off the west coast of British Borneo for the Brunei Shell Petroleum Company.

Pattern of World Oil

Although there are now some fifty countries listed as oil producers, about 90% of the world's total oil is produced in four geographical areas, i.e., the U.S.A., the Caribbean, the Middle East and the Soviet Union. Increasing attention has been devoted in recent years to estimates of world oil reserves, as it is more and more realized that the oil reserves of to-day are the store-house of to-morrow. These reserves are usually divided into three categories, i.e., "proven", "probable", and "possible" reserves. The figures given in Table II show the pattern of the world's estimated reserves of crude oil since 1925.

TABLE II: ESTIMATED PROVEN RESERVES OF CRUDE OIL (IN MILLIONS OF BARRELS)

YEAR	U.S.A.	WORLD
1925	7,500	—
1935	12,177	23,000
1945	19,785	64,000
1950	24,649	80,000
1955	29,561	158,000
1956	30,012	190,000
1957	30,434	228,000
1958	30,300	261,000
1959	30,536	272,000

Of the latest world total, about two-thirds is contained in the Middle East. It should also be noted that the figures given in Table II do not include natural-gas liquids. In the U.S.A. these are known to be considerable, and reserves were estimated at 6,204,000,000 barrels at the beginning of 1919. No attempt has been made in other countries to estimate the reserves which may be available from this source.

In fact, proven reserves represent only a portion of the actual world oil reserves. These, in addition to proven reserves, include possible reserves, but, whilst proven reserves are based on calculations proceeding from known factors which ensure a fair measure of accuracy, possible reserves, although based on reasoned conjecture and containing a certain element of reliability, are no more than very rough indications.

American oil expert, Mr. Lewis G. Weeks, in the Bulletin of the American Association of Petroleum Geologists, recently estimated total world potential for liquid petroleum resources, "recoverable by conventional primary methods in terms of current economics", as about sixteen times the oil which has already been produced. He considers that about the same quantity may also ultimately be recovered by secondary methods. If this is correct, we have no cause for immediate worry, providing that exploration is continued with energy and pertinacity.

Another expert estimate, recently published by Mr. N. L. Falcon, Chief Geologist of the B.P. Exploration Co., Ltd., gave the following figures regarding the ultimate potential reserves of liquid petroleum (in millions of barrels).

World ultimate potential	1,500,000
Already produced	93,000
Already proved	325,000
Possible reserves (land)	882,000
Possible reserves (undersea)	200,000
Ultimate potential reserves, U.S.A.	250,000
Ultimate potential reserves, U.S.S.R. and Satellites	250,000

The trend of oil consumption shows a steady increase throughout the world, except in Canada, where a 2% decline was registered during the period under review, as illustrated in Table III, which shows world oil consumption for 1958, compared with that in 1957, in millions of tons (1 ton of oil = 7·5 barrels).

TABLE III: WORLD OIL CONSUMPTION 1958 AND 1957 (IN MILLIONS OF TONS)

COUNTRY	1958	1957	1958 SHARE OF TOTAL
U.S.A.	437	425	47%
Canada	36	37	4%
Mexico	13	13	1%
Caribbean	18	18	2%
Others	47	45	5%
TOTAL WESTERN HEMISPHERE	551	538	59%
Western Europe	156	136	17%
Africa	29	28	3%
Middle East	20	19	2%
East Indies	7	6	1%
Australasia	11	11	1%
Others	42	40	4%
Eastern Hemisphere, excluding U.S.S.R., etc.	265	240	28%
U.S.S.R., etc.	117	104	13%
TOTAL EASTERN HEMISPHERE	382	344	41%
World, excluding U.S.S.R., etc.	816	778	87%
World, including U.S.S.R., etc.	933	882	100%

The Status of America in Oil

The outstanding development in the world oil industry following World War II, has centred round the fundamental changes in regard to the position of the U.S.A. domestic oil industry in relation to the rest of the world.

Prior to 1939, by the sheer size of her domestic output, the U.S.A. dominated the world market, but the dynamic upsurge of oil production in the Eastern Hemisphere brought about a sharp re-orientation of world oil conditions.

In 1938, the U.S.A. share of the total was 61%. Thus, America produced more oil than the rest of the world put together, though, if one goes back as far as 1901, Russia did, for a short time, surpass her.

By 1957, although America's production had risen from 168,000,000 to 380,000,000 tons, her share of the world total had fallen to 42%. Russia's share, on the other hand, has changed only about 1%, standing to-day at around 11%, as compared with about 10.3% in 1938. This indicates the very rapid growth of production in other areas over the last twenty years, particularly the Middle East, which rose from 16,000,000 tons in 1938 to an equivalent of 193,000,000 tons in the second half of 1957. The pattern which now emerges, calculated on 1957 production figures as a percentage of the total world production of nearly 900,000,000 tons, is as follows:— U.S.A. 42%; Middle East 19%; Caribbean 17%; Russia and Satellites 12%; Canada 3%; East Indies 2%; Others 5%.

Of America's forty-nine states, thirty-two are oil producers, their annual outputs (including natural gas) varying from some 160,000,000 tons produced in Texas to only 2000 tons in Virginia. In 1957, two states, Texas and California, together supplied more oil than the combined output of the Middle and Far East, and several other states also produced more than many important oil-producing countries. Thus, the individual outputs of Louisiana, Oklahoma, and Kansas ranged between

46,000,000 and 17,000,000 tons; by comparison, Canada produced about 25,000,000 tons, and Mexico some 13,000,000 tons in 1957.

During the past hundred years, the daily average U.S.A. oil output has risen from Drake's modest 8 to 10 barrels in 1859 to the stupendous total of very nearly 7,000,000 barrels in 1959.

Pennsylvania and the neighbouring states of New York, West Virginia, Ohio, and Kentucky, were the cradle of the oil industry and, for a quarter of a century after Drake's well, remained the major source of U.S.A. supplies. To-day, however, the output of oil in this area (which includes such cities as New York, Pittsburgh and Philadelphia), is under 2% of the total U.S.A. production, and does not even cover its own needs.

The major oil-producing states now are Texas, California, Louisiana, Oklahoma, and Kansas, in a vast oil-producing region extending from the Gulf of Mexico to the centre of the U.S.A., and from Illinois in the east to the fringe of the Rocky Mountains area. Texas is not only the largest state in the Union but also it is by far the largest oil producer, its output reaching in 1957 about 160,000,000 tons.

America's refinery capacity now stands at about 450,000,000 tons per annum, and the number of her refineries, giant and small together, is about 300. Of the total U.S.A. refining capacity, Texas represents over 120,000,000 tons a year. The average consumption of oil per head of the population was 600 Imperial gallons in 1956, compared with about 120 gallons in the U.K.

Despite the diminished part played by U.S.A. domestic production of oil in international trade, American capital has continued to remain an extremely powerful factor in post-war oil developments throughout the world. Of the seven major groups dominating the world oil scene, five are American. These are the Standard Oil Company (New Jersey), by any yardstick the largest of all oil companies in the world, and the most important single unit which emerged when the mammoth Rockefeller oil empire was dissolved by order of the Federal Supreme Court in 1911; the Texas Company and Standard Oil of California, its partner in the Eastern Hemisphere operations of the California-Texas Corporation (Caltex) group; the Gulf Oil Corporation, whose major interests outside the U.S.A. are in crude-oil production in Venezuela, Kuwait, and Sicily; and finally the Socony-Vacuum Oil Inc., which has a joint subsidiary in Standard-Vacuum, operating East of Suez.

The two non-American major companies are the Royal-Dutch-Shell group (headed by the holding companies, N. V. Koninklijke Nederlandsche Petroleum Maatschappij (Royal Dutch), and Shell Transport and Trading Co., Ltd., which share the interests of their groups in the proportion of 60 and 40% respectively), challenged in its huge global interests olny by the Standard Oil Company (New Jersey) and the British Petroleum Company, the largest producers of Middle East crude oil, with interests in about a hundred subsidiaries and associates of various kinds. The two latter groups enjoy a strong postition in Eastern Hemisphere markets, in some of which, notably in the U.K., they operate joint marketing subsidiaries.

The seven major oil groups enjoy a status of immense importance in the world refining industry, corresponding to that of their standing in regard to the marketing of oil. Nevertheless, there has been a noticeable broadening of independent interests in the search for oil, mainly in the Sahara Desert and other North African areas.

Latin-American Oil

After World War I, the greatly stepped-up production of Mexican oil was one of the principal factors which helped to assuage the oil famine that had ensued in the years immediately following the cessation of hostilities, and similarly, after World War II, it fell to Venezuela to make an important contribution to world economic recovery by making good a similar shortage.

However, in the inter-war years, which had seen the sinking of tremendous amounts of foreign capital into the quest for oil in South America, the oil scene there was steeped in distrust, rivalry, and intrigue, fomented by intense nationalism. Various political factions exploited South American fears of becoming the victims of American or British oil imperialism, and in several of these countries hostile legislation, in some cases nationalization of foreign-owned oil assets, for long retarded the proper development of Latin-American oil.

The single exception was Venezuela, where foreign participation was welcomed and encouraged. Big oil discoveries were made there in 1922 and, by the mid-1930's, Venezuela occupied second place in the ranks of the world's oil-producing countries, and is now by far the largest oil exporting country in the world.

Before the war, Venezuela was already challenging the position of the U.S.S.R. as the world's second largest producer, and since 1938 her production has been quintupled, reaching a record level of about 145,000,000 tons in 1957, when Venezuelan output was more than double that of any other country outside the U.S.A. and the Soviet Union. Venezuela, indeed, derives approximately two-thirds of her entire internal revenue from royalties and taxes on oil, and the operations of British and American oil companies provide her with substantial amounts of foreign currency.

Latest available figures show that Venezuela oil exports, which account for well over 90% of her total exports, are greater than all her imports and, thanks to her oil trade, Venezuela is one of the few countries in the world which has no external debt.

There was a time when, in 1921, Mexico supplied a quarter of the world's oil production. In 1928, however, the fields began to yield salt water, mainly as a result of too rapid development, in an attempt to supply as much as possible of the world's rising demand for oil. This decline was later partially offset by subsequent discoveries and, although her exports are still appreciable, they were exceeded in 1937 by her imports, owing to her increased home consumption.

In the Caribbean area, Colombia also produces oil, and other important Latin-American oil-producing countries are Argentina, Peru, and Brazil, with Chile, Bolivia, and Ecuador well behind.

Although the knowledge and use of oil seepages in South America are very ancient, commercial production is a comparatively quite recent development. The first recorded production was in Peru around 1870 and, as early as 1888, British operators were operating small oil fields there.

The main Latin-American oilfield areas were located by British, Dutch and U.S.A. oil companies, which still carry on production, in exemplary harmony, in Venezuela and several other countries, except in Mexico and Bolivia, where all foreign oil properties were expropriated in 1937 and 1938 respectively. In Argentina, too, certain oil areas are reserved exclusively for operation by a Government owned company; in Brazil and Chile the oilfields

are also Government-controlled. Very recently, in 1955, the position has changed in Bolivia, where under the new Petroleum Law, foreign capital has been re-admitted.

There are still vast areas of potential oil-bearing lands in Latin-America awaiting exploration, but, except for Mexico and Venezuela, the remoteness of some of the potentially promising regions from the sea or from other means of transportation has greatly impeded the pace of oil development.

Treasures of the Middle East

Age-old seepages in Persia and Mesopotamia (now Iraq) long ago indicated the presence of rich oil areas, but it was not before the turn of the century that the dramatic developments, climaxing in the discovery of the priceless oil treasures of the Middle East, began to be unfolded, eclipsing even the most fascinating stories in the fabulous Arabian Nights.

William Knox D'Arcy, a solicitor of Rockhampton, Queensland, Australia, who had made a great deal of money there in gold mining, succeeded in 1901 in obtaining a concession of 480,000 square miles for oil exploration in the South Eastern provinces of Persia. After years of fruitless efforts and after spending some £225,000 of his own money, he was forced to look for fresh funds.

Eventually, it was the old-established Burmah Oil Company, founded in 1886, who came to his rescue in 1905 by providing finance, management, staff, and technical "know-how". Years of arduous work and unremitting efforts were crowned with success in 1908 by the discovery of the rich Masjid-i-Sulaiman ("Temple of Solomon") gusher. The immediate sequel was the setting up of the Anglo-Persian Oil Co., to develop the concession, and a huge refinery plant was built on a nearby barren mud-flat at Abadan. The new Company was almost 100% owned by the Burmah Oil Co., until the British Government acquired a majority interest in it just prior to the outbreak of World War I.

By the beginning of World War II, Persian oil production reached an annual total of 10,000,000 tons, rising by 1951 to 32,000,000 tons, when the Teheran Government enacted legislation for the nationalization of the oil industry, including the Abadan refinery.

Following a long impasse and tedious international negotiations, an agreement was signed in 1954 between the newly set up National Iranian Oil Company and an international consortium for the division and working of the Persian oil properties. Under the terms of this agreement, the main oilfields, together with the Abadan refinery, are worked by two companies incorporated under the laws of the Netherlands representing a consortium of British, Dutch, U.S.A. and French interests. The companies are solely responsible for all operations over a wide area, and exercise their powers on behalf of Persia's national oil company.

Expectations that Iraq would prove to contain substantial petroleum deposits led to keen competition for a concession around the turn of the century, when the country still formed part of the Ottoman Empire. Before and immediately after the 1914-18 war, British, Dutch, German and finally French and U.S.A. interests all sought concessions over a wide area in Iraq. In the end, this was granted to an international group representing all of these several interests, with the exception of the German group. Drilling commenced in 1927 and, in the same year, oil was discovered at Baba Gurgur—the well which brought in the great Kirkuk oilfield, which over the next thirty years was to produce 200,000,000 tons of oil.

Nevertheless, the entire enterprise was hampered by complicated negotiations, involving a great deal of international intrigue and "cloak and dagger" diplomacy, until a successful conclusion was reached at the end of 1928, very largely because of the efforts of the late Calouste S. Gulbenkian. The upshot was the formation of the Iraq Petroleum Co.—the successor to the Turkish Petroleum Co., founded in 1912—95% of the shareholding being divided between the Anglo-Persian Oil Co. (now British Petroleum Co.) Shell Cie Française des Petroles, and the Near East Development Corporation (a joint undertaking of the Standard Oil Co. (New Jersey) and Socony-Vacuum). The remaining 5% of the shares were purchased by Gulbenkian and were not, as popularly supposed, allotted to him free in recognition of his services. This investment yielded Mr. "Five Percent" Gulbenkian many millions of pounds, resulting in the recent establishment of the great Gulbenkian Foundation.

After the last war, exploration in Southern Iraq proved so successful that Iraq is now the fourth largest petroleum producer in the Middle East, her output having risen five-fold between 1950 and 1958 and, in the opinion of experts, likely to double this amount by 1961.

But perhaps the most glittering fairy tale in the rich panorama of petroleum is that of the little sheikdom of Kuwait, a sparse desert area about the size of Wales, with only just over 200,000 inhabitants. Since 1946, when the first shipment of oil from Kuwait began, she has become the fourth largest oil producing country in the world and the second largest exporter of crude oil, yielding pride of place only to Venezuela. From her very modest start in 1946, Kuwait's output of oil has now reached 70,000,000 tons a year.

Survey work to ascertain the existence of promising oil-bearing formations in Kuwait began in 1935 but, owing to the war, it was not possible to continue drilling till after 1945. In 1934, the Kuwait Oil Company was formed jointly by Anglo-Persian and the Gulf Oil Corporation and it was under the equal partnership of this Anglo-American combination that the discovery of what is now the Burgan oilfield was completed. After the interruption caused by the war, work was resumed in October 1945 and, by the summer of the following year, Kuwait began to export, mainly to Western Europe, and to Britain in particular, her liquid treasures.

Another fascinating Middle East romance is that of Saudi Arabian oil. In 1936, the Arabian American Oil Co., was formed and, two years later, exploration work was completed. Again, the war interrupted production, but, during the years 1941 to 1945, further oil discoveries were made in the country, and by 1955 it was realized that five major oil-bearing areas—from Ain Dar to Haradh—which had been classified as separate fields, in reality constituted one vast oil region measuring 130 miles in length, known collectively as the Ghawar field.

By 1952 output in Saudi Arabia exceeded 40,000,000 tons, and over the past few years it has amounted to nearly 50,000,000 tons annually. The country thus ranks as the fifth largest producer in the world, but, as in the case of Kuwait, potential yield is greatly in excess of existing output, and at the end of 1957 it was estimated that Saudi Arabia's proven oil reserves were greater than those of the U.S.A., which in that year provided over 40% of the total world output.

Between Kuwait and Saudi Arabia lies a neutral zone, over which each country possesses equal rights. Oil

concessions over this territory have been granted to U.S.A. oil interests, and drilling was first initiated in 1949, oil being discovered at Wafra in 1953. Whilst production does not compare with that of the two neighbouring countries, by 1957 it amounted to over 3,000,000 tons and, as a result of additional development work, is expected to reach a higher level in future.

Oil has also been found in Bahrein Island, in the Qatar peninsula, and in Syria, where exploration work is still going on. Egypt is a large consumer, but a comparatively small oil producer. Since 1954 Turkey has been permitting the participation of private foreign companies in the intensive oil exploration going on in various areas of the country.

Both the Government and various private concerns have been actively engaged in the search for oil in Israel for a number of years, and production was established at Heletz in 1955—on a site where drilling had been commenced many years earlier and suspended on account of the outbreak of war between Israel and the Arab League in 1948. Additional oil resources have been discovered at Bror and these may prove to be an extension of the Heletz formation. The yield obtained from Heletz is very small, but, in view of Israel's economic problems, is most welcome. Deposits of natural gas have also been located in Israel.

Meanwhile, oil exploration parties are carrying on immense sweeps of the sandy wasteland of the Algerian Sahara and the Libyan Desert, both of which are slowly beginning to yield up their secrets. There is already ample evidence that they may yet prove to be among the major oil-producing areas of the world. Exploration of the Algerian Sahara has already led to the discovery of four major oil and natural (petroleum) gas zones in widely separated regions. The ultimate potential of this area in terms of oil resources cannot as yet be more than guessed.

Oil Behind the Iron Curtain

Russia, covering one-sixth of the earth's surface, is the third largest oil-producing country in the world, coming after the U.S.A. and Venezuela. Oil has been known in Russia for many centuries, and Marco Polo, when he visited Baku—then part of Persia—described in his "Travels" how "a great fountain of oil which discharges so great a quantity as to furnish loading for many camels. The use of it is . . . as an unguent for the cure of cutaneous distempers in men and cattle, as well as other complaints, and is also good for burning."

By the time Peter the Great ruled in Russia, there was quite a brisk trade in oil up the Volga River. Nothing very much, however, happened in this direction until the latter half of the nineteenth century, when American petroleum was introduced into Russia in 1862, where it speedily established itself as the leading illuminant.

After some oil finds in southern Russia and the introduction of American drilling methods, Russian production increased rapidly, and, following the invitation by Russia in 1872 to foreign capital to participate in the development of the country's oil resources, the backing of the French branch of the House of Rothschild and of the distinguished Nobel family, resulted in such a rapid expansion of production, that for some time in the early years of the present century Russia even challenged the position of the U.S.A. as the world's leading oil producer, her production in 1901 reaching over 11,000,000 tons.

Even before the U.S.A., Russia went in for bulk transportation of oil by water, and a semblance of the modern tanker appeared on the Caspian Sea as long ago as 1877; gradually, a whole fleet of these tankers began plying the Caspian, the Volga River, and the Baltic Sea.

After years of fluctuating output, Russian production took an upward turn after World War II, and by 1947 her annual output topped the 100,000,000-ton mark; under the Sixth Five-Year-Plan, production by 1960 is expected to reach the total of 135,000,000,000 tons.

Soviet oil is produced in several widely separated regions, of which the most important, namely, the Caucasian and the Volga-Ural-Emba fields, are west of the Urals. The production of the Asiatic oilfields, which include those on Sakhalin Island off the east coast of Siberia, is relatively small.

Russia's probable oil reserves have been estimated by the Russians themselves at 4,500,000,000 tons, and the Soviet oil industry is continuing to make great efforts to increase production. It is actively pursuing exploration in many widely separated areas of the country, including Siberia and the Crimean Peninsula, and there have been reports of recent discoveries of new oil deposits.

The present Five-Year-Plan (1955-1960) places considerable emphasis on the completion of further trunk oil pipelines and, during this period, pipelines totalling 9000 miles will be added to a system which in 1955 totalled 7000 miles. The plan also provides for large-scale development of the use of natural gas.

To-day, Russia uses more oil than any other country, except the U.S.A. and, although she was once a greater exporter—with a peak of 6,000,000 tons of oil exports in 1932, when indigenous production was under 22,000,000 tons—the level of exports fell to under 2,000,000 tons only five years later, though production was then over 27,000,000 tons; by 1939 Russia had practically vanished from the international oil market.

In the years following the war, which for some time adversely affected output, no appreciable export of oil occurred, and there was a rapid increase in domestic demand, owing to the growing development of industry and the mechanization of agriculture. In the beginning, motor transport expanded slowly, as compared with progress in many other countries, and in 1938 there were only about 600,000 commercial vehicles and less than 100,000 passenger vehicles in Russia: by 1957, however, the figure had risen to over 3,000,000 vehicles of all types.

Expansion in the use of oil in the next few years is likely to continue, and some indications of the probable trend of future Russian demands can be gained from a study of plans for industrial development published in connection with the Sixth Five-Year-Plan, under which total industrial output by 1960 is scheduled to be 65% above the 1955 level. This plan also provides for an increase in the production of motor vehicles from 445,000 in 1955 to 650,000 in 1960, and a rise in tractor output from 248,000 to 322,000 in the same period, with diesel-engine units preferred for reasons of fuel economy. Provision is also made for the extension and modernization of railway facilities, the output of diesel locomotives being scheduled to increase, although only 1630 will be in service by 1960.

Outside the Soviet Union, the only important oil producer in the Soviet bloc, apart from Poland, is Roumania, whose output last year amounted to 11,500,000 tons. By 1960 she is expected to produce 13,500,000 tons. Roumania refines all her oil domestically and exports about half. In 1956, some 60% of her exports went to the Soviet Union, which re-exported most of them. The remainder was sent largely to Western Europe and Egypt.

Oil in the Far East

Perhaps the most interesting feature of the oil industry in the Far East is its extreme antiquity. Burmese oil, mentioned in Chinese writings of the 13th century, had become a leading commodity in national and international trade many decades before James Young had begun his experiments for refining mineral oils in England, or the first oil well had been drilled in the U.S.A., but these Burmese wells were not drilled, being dug by hand to depths of several hundred feet and lined with timber.

The Burmese oilfields, lying along the Irrawaddy River, were worked by the Twinzayos, hereditary heads of a group of twenty-four families. The oil was distributed throughout the entire country, large quantities being transported down the river to Rangoon. In the middle of the last century, Burmese oil was even exported to England for manufacture into lubricants and paraffin-wax.

As long ago as 1886, the Burmah Oil Co. commenced operations, and their pioneering achievements include the construction in 1908 of the Burma main pipe line—in its day one of the longest large-diameter oil lines in the world—and the complete electrification of the central Burma oilfields (in conjunction with other principal oil companies). Its original producing and refining facilities in Burma are now operated in partnership with the Burmese Government.

War damage resulted in the total destruction of Burma's industry, but the state of the country has recently improved and exploratory drilling has recommenced.

In ancient China, where oil was discovered in the province of Szechuan in the course of working brine deposits, a system of drilling was evolved which closely resembled the " cable-tool " or " percussion " method of drilling used by the American oil pioneers. The Chinese are believed to have drilled for oil more than two thousand years ago and, although they had no mechanical power sources, the average depth of these wells was over 1500 ft, one well reaching 3000 ft.

Oil production in the Far East, though overshadowed by that in North America, the Caribbean, the Middle East and the U.S.S.R., is nevertheless of considerable importance. The oilfields in this region supply the major proportion of the oil requirements of the Far East and Australasia, and output is steadily increasing after the temporary breakdown during the war years.

The Far East possesses substantial reserves of oil—notably in Indonesia, main source of pre-war oil production, and in British Borneo—though admittedly these reserves appear small in comparison with those of the world's four major oil regions.

Consumption in the countries of the Far East is generally low in relation to their large populations. For example, in China, where petroleum is still utilized mainly in the form of kerosene for lighting, it amounts only to about one Imperial gallon per head per annum, as compared with 122 Imperial gallons in the U.K. and about 600 Imperial gallons in the U.S.A.

In Australia and New Zealand, on the other hand, consumption is at a comparatively high rate and, both there and in the Far East, industrialization and other developments will involve a steady increasing demand for oil in the future.

India, Pakistan, Japan, and China all supply part of their individual oil requirements. Owing to the low level of oil consumption in most Asiatic countries, the total pre-war requirements of the Far East and Australasia amounted to only about 13,000,000 tons annually. Japan (3,500,000 tons), India and Burma (2,200,000 tons), Australia (just over 2,000,000 tons), and Indonesia (just over 1,000,000 tons) were the largest users.

Britain's Stake in Oil

Traces of oil and natural gas in Great Britain have been recorded from very early times; thus, a tarry oil, found saturating many of the rocks in Shropshire, was used as pitch by the Romans. However, only a fraction of Britain's oil needs comes from indigenous sources, the annual consumption being about 25,000,000 tons and production some 600,000 tons, the latter figure comprising largely the refined oils produced as a result of treatments of coal and shale and some 80,000 tons of crude oil produced in Britain. The bulk of Britain's requirements is met by the refining of imported crude oil in numerous refineries which have been expanded and erected since the war at an estimated total cost of well over £300,000,000.

In 1911, interest in the possibility of indigenous petroleum resources was stimulated by the discovery of crude oil in a borehole sunk in the course of coal-mining operations near Newark, Notts. As a result, the first steps were taken to determine the potentialities of Britain as a source of crude petroleum, and in 1919 Britain's first producing oil well was completed at Hardstoft, Derbyshire. The Hardstoft field, however, proved to be of very minor importance.

Early in 1958, a new field was found in Lincolnshire, near the Nottinghamshire border. There is also a very small contribution from Formby, Lancashire, and a little from Dalkeith, near Edinburgh. Small quantities of oil are derived from one or two other places.

Until World War II, British oil needs were provided mainly by importing refined products, the Caribbean being the premier source of supply, and only a comparatively small proportion of crude oil was shipped to the U.K. for processing. After the war, however, the oil industry in Britain embarked on the building of a number of huge refineries, and the U.K. refinery industry has grown during the past ten years beyond all recognition.

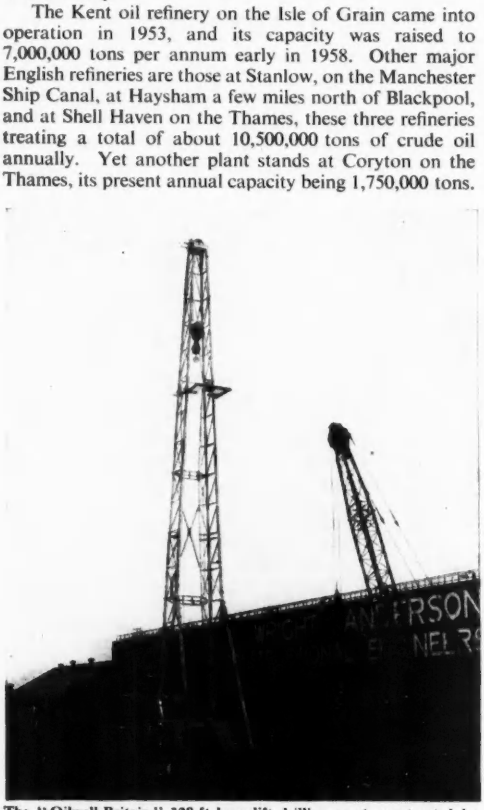
It is a far cry from Kier's 1860 one-barrel still to the mammoth refineries of 1959. These modern refineries cover an area equal to that of Salisbury's historic plain, yet there is little audible evidence of life in the huge maze of installations. Unseen and practically unheard, rivers of feedstock and finished products flow from one installation to another, until the cycle of treatment is complete and the various derivatives are diverted to their respective storage tanks. Thence, by coastal tanker, pipeline, rail-car or road-tank wagon, the products are speeded to the consumer.

By 1954, Britain's total refining capacity had been multiplied more than tenfold, as compared with the level of 2,500,000 tons in 1947, and now is nearing 40,000,000 tons per annum. All these new refineries are located on the coast or its immediate vicinity and have deep-water harbours to enable tankers to come straight to their wharves.

One new plant, at Fawley, close to Southampton, was completed in 1951 at an expenditure of £37,500,000 and covers an area of about 1000 acres. This plant, at present the largest in Europe, processes some 10,500,000 tons of crude oil per year. One of the recent developments at Fawley has been the construction of a special plant for the production of butadiene, used for the production of

a synthetic rubber in a plant established by the International Synthetic Rubber Company. By the end of this year, this new plant will be capable of producing 70,000 tons annually.

The Kent oil refinery on the Isle of Grain came into operation in 1953, and its capacity was raised to 7,000,000 tons per annum early in 1958. Other major English refineries are those at Stanlow, on the Manchester Ship Canal, at Haysham a few miles north of Blackpool, and at Shell Haven on the Thames, these three refineries treating a total of about 10,500,000 tons of crude oil annually. Yet another plant stands at Coryton on the Thames, its present annual capacity being 1,750,000 tons.



The "Oilwell-Britain" 128-ft lever-lift drilling mast, constructed by Wright Anderson Ltd. in conjunction with the Oil Well Supply Co. Ltd.

Two more large-scale refineries are in existence in Britain. One of these is at Llandarcy, in Wales, not far from Swansea, and at the end of 1957 had an operative throughput of some 3,000,000 tons. The second refinery is at Grangemouth, near Edinburgh. This Scottish plant has an annual capacity of 2,200,000 tons, but is being expanded by around 50%.

Although the total throughput of all British refineries is substantially in excess of present domestic requirements, so that appreciable quantities of refined products are exported, plans have been evolved for even further expansion. Thus, a completely new refinery, capable of treating 4,500,000 tons of crude oil annually, is under construction at Milford Haven in Pembrokeshire. Work commenced on this project about the middle of 1958, and it is anticipated that it will be completed in 1960.

British companies, either alone or in association with foreign companies, are concerned in the production of oil in most parts of the world, even in the U.S.A., where naturally production is chiefly American, there are substantial British interests involved in oil production.

Concurrently with the post-war development of Britain's oil-refining resources, a brand-new British industry has come into being for the supply of specialized equipment for the world's oilfields. This development was sparked off by the fact that, as no dollars were available after the war for the purchase from traditional American sources, such as the giant Kellogg and Lummus companies, of equipment needed in connection with the building of the great refineries, Britain was forced to produce it herself. To-day, British firms are making portable drilling rigs, pumping units, collars, and fractionating columns, to mention but a few items.

Although this virile new British industry is now producing oil equipment which until quite recently was obtainable only in the U.S.A., due credit must be given to the enlightened attitude of the American oil-equipment industry for its generous co-operation in granting commercial licences to British firms for the manufacture of certain items of equipment, thereby practically making it an Anglo-American industry in these islands.

A typical example of this Anglo-American production is the "Oilwell-Britain" lever-lift drilling mast, completed recently by Wright Anderson Ltd., in conjunction with the Oil Well Supply Co., Ltd., the American parent company of which was founded in Titusville, in 1862. This British-made 128-ft mast is the first to have been built and raised anywhere in the world. Similarly, another recent British success in the oil-equipment field is the production by British Insulated Callender's (Submarine Cables) Ltd., of a flexible reinforced plastic pipeline, particularly suitable for submarine pipeline installations.

To illustrate the remarkable success of this new industry, it may be mentioned that, in 1958, British firms received orders for oil equipment and materials (exclusive of tankers) to a value of over £122,000,000 while, during the past four years, orders amounted to no less than £500,000,000, of which 80% comprised exports for use by British and foreign companies.

Oilfields in the Commonwealth

The British Commonwealth is the world's second largest user of oil products, its consumption being exceeded by that of the U.S.A. alone; however, whereas the U.S.A. is also the world's chief oil producer, the few proven oilfields within the Commonwealth are quite inadequate to its needs. Though British companies have large interests in important oil-producing countries overseas, unremitting efforts are also being made to discover fresh oilfields within the Commonwealth itself.

The main oil-producing areas of the Commonwealth are Canada, British Borneo and Trinidad. As shown in Table IV, these three are the only territories within the Commonwealth producing as much as 1,000,000 tons of crude oil per year (including natural gasoline, but excluding the small production from coal and shale).

To-day, Canada ranks eighth among the world's leading oil-producing countries but, although her first oilfields were developed in the 1860's, Canadian output

TABLE IV: COMMONWEALTH OIL PRODUCTION (IN TONS)

COUNTRY	1956	1946	1938
Canada	23,650,000	1,000,000	900,000
British Borneo	5,800,000	300,000	900,000
Trinidad	4,180,000	3,000,000	2,600,000
India	390,000	300,000	400,000
Pakistan	300,000	—	—
United Kingdom	60,000	60,000	—
Others	—	—	1,100,000*
TOTALS	34,380,000	4,660,000	5,900,000

*In 1938, Burma was included in the Commonwealth, but has now left.

remained small for many decades and, indeed, until 1949 never reached an annual total of 2,000,000 tons. This rather gradual development of her oil resources was undoubtedly influenced by the availability of abundant supplies of oil from other sources, especially the U.S.A.

British Borneo, which includes the territories of British North Borneo, Brunei, and Sarawak, forms the northern part of the island of Borneo, the bulk of oil supplies coming from the Miri field in Sarawak and the Seria field in the State of Brunei. Oil production in British Borneo was seriously disrupted by the war and, after the Japanese retreat in 1945, production had to be built up again almost from the very beginning. Rapid post-war developments have raised production in British Borneo far above the level of 1938 and, before the end of 1948, made it the largest oil-producing country in the Commonwealth after Canada.

The island of Trinidad first attracted attention on account of its remarkable Pitch Lake, noted by both Christopher Columbus, who in 1498 caulked his ships with Trinidad pitch, and by Sir Walter Raleigh, who called at Trinidad almost a hundred years later. The "clean" asphalt from this lake forms one of Trinidad's main exports to Great Britain, where it has long been used for road-making and other purposes. The Trinidad oilfields, however, are a much more recent discovery and, though abortive attempts were made to produce oil in Trinidad in the last century, commercial production only started in 1909.

The main centre of the Trinidad oil industry is in the south-west of the island, though minor Trinidad oilfields have been discovered elsewhere. In all, about twenty oilfields are now producing, but these are generally of medium depth, of small size, and in no way comparable, for instance, with those of Venezuela, whose most eastern fields lie only a few miles away across the Gulf of Paria, which separates Venezuela from Trinidad. Trinidad produces only some 5,000,000 tons a year, but as she has only a small domestic demand, most of the products from her crude oil, which is refined locally, are exported. Despite her comparatively small output, for many years Trinidad was the largest oil producer in the Commonwealth, losing its position to British Borneo towards the end of 1948.

Energetic exploration for oil has been carried on in India, and led to the discovery by the Assam Oil Company of an oilfield at Nahorkatiya in 1953, claimed to have large reserves but not yet fully developed. The Punjab oil-producing areas are now part of Pakistan, and an ambitious programme of oil prospecting has already led to the discovery of one of the largest single natural-gas reservoirs in the world at Sui, by Pakistan Petroleum Ltd.

More than twenty years of assiduous search culminated recently in the discovery of oil in Nigeria in commercial quantities at Oliobiri, in eastern Nigeria, about eighty miles west of Port Harcourt, and export of oil from Nigeria, albeit on a modest scale, was initiated early in 1958.

After years of very meagre oil production, amounting to not more than a few hundred tons per year, oil was reported to have been located in 1953, near Exmouth Gulf, about 700 miles north of Perth, Australia. The wells so far drilled, however, have been disappointing, and it is more than doubtful whether commercial production will ever be achieved there.

Finally, apart from the infinitesimal quantity produced in the U.K., only a few traces of oil have been found in other parts of the Commonwealth.

Oil in Western Europe

Western Europe, with its highly developed transport system and its many industries, is one of the world's major oil-consuming areas. Since, however, indigenous resources are comparatively small, this region is mainly dependent on imports to satisfy its steadily expanding requirements.

It is true that there are altogether seven countries in Western Europe where oil is produced, but all the fields so far discovered are comparatively small and there are indications that local geological factors are not at all favourable to the existence of the larger type of oil-bearing formation.

Until World War I, Austria produced an appreciable quantity from the Galician oilfields, which subsequently became part of the newly-established Polish republic. Oil exploration in other parts of Austria occurred both during and after World War I and incidentally was marked by the world's first geophysical oil survey, carried out in the Vienna Basin between 1915 and 1916. Exploration in Austria has been extended in recent years to other areas, and in 1956 oil was discovered at Puchkirchen, midway between Linz and Salzburg—the first oil to be found outside Lower Austria. This field is still being developed and its importance cannot yet be assessed.

The earliest discovery of oil in Germany was made in Hanover in 1876, and further finds occurred during the ensuing half-century, though the level of output remained comparatively low for many years, and in 1957 production was still below 4,000,000 tons.

Although oil had been found in Pechelbronn, in Alsace, as long ago as the 15th century, oil production in France, despite some recent finds in the Parentis and Lacq areas, never reached a high level, the output in 1957 amounting to just below 1,500,000 tons.

Holland's production per annum is very slightly higher than that of France, though oil strikes were reported in 1953 near The Hague and subsequently between The Hague and Rotterdam.

Petroleum has been known in Italy since the days of the Roman Empire, and Pliny was one of several writers who mentioned commercial production from seepages and hand-dug pits two thousand years ago. The oil was put to many uses, and it is also believed that early Roman camps in the neighbourhood of the ancient town of Villeja were heated by means of natural gas. Although utilization of petroleum continued during the Middle Ages, and in 1820 Genoa and several other towns were employing oil-burning lamps for public heating, attempts to establish large-scale production are comparatively recent.

Italy's first major oil discovery, however, occurred outside the mainland—at Ragusa, in Sicily. This event was of especial importance because it indicated that oil could be produced from a particular type of formation commonly found in the Eastern Mediterranean. Development in Sicily has been rapid, and by 1957 Ragusa, together with the newly discovered Gela field in Sicily, accounted for nine-tenths of Italy's total production of just over 1,250,000 tons. Exploration work is continuing in Sicily and also on the mainland, where, however, operations are hampered by the mining laws which, *inter alia*, reserve concessions in the promising Po valley area to the State-owned oil concern. Although a new petroleum law came into force in Italy in 1957, this confirmed the virtual State monopoly in the Po valley and also placed severe restrictions on all remaining

operators, even in other regions. In addition, royalty scales laid down were in excess of the conventional "fifty-fifty" profit-sharing arrangements current in the Middle East and other oil-producing countries. In Sicily, very different laws govern operations and these have given greater incentive to U.S.A. and other private oil companies to participate.

In Yugoslavia, small amounts of oil were located during the inter-war years. Activities were intensified after the discovery of oil in neighbouring Hungary in 1939, and additional oil supplies were found in Yugoslavia during the war. Subsequently, a number of new fields have been discovered, and although none has proved of major importance, production has been rising steadily and in 1957 totalled about 400,000 tons.

Post-war difficulties over coal supplies, combined with an increasing level of industrial activity, have caused the oil needs of Western Europe to rise rapidly during the past decade. Whereas in 1947 inland consumption in the O.E.E.C. area totalled only 35,000,000 tons, with widespread rationing of certain products, by 1956 the figure had risen to 108,000,000 tons, an increase of over 200%, during a time when oil demands from the rest of the world approximately doubled. This growth was by no means confined to the earlier years, when Europe was recovering from the effects of the war, and between 1955 and 1956 alone there was a 15% rise in the use of oil. During 1957, consumption rose slightly to 109,000,000 tons, despite the fact it was artificially restricted for some time owing to the effect of the Suez crisis on supplies.

The Promise of To-morrow

It is well-nigh impossible to imagine the havoc that would result were the oil wells by some catastrophe to run dry, and, although atomic energy will take an increasingly growing share in the provision of power and energy, oil will continue to keep the world's wheels turning and to provide man with energy for his daily expanding requirements for a long time to come.

The oil industry is envisaging the time, possibly within the next twenty years, when an annual output of between 1,500,000,000 and 2,000,000,000 tons of oil will be necessary to cope with prevailing demands and, subject to two conditions, the industry is in no doubt that it will be equal to the task. Firstly, it requires prudent handling and conservation of its profits for financing expanded operations; secondly, it must enjoy the greatest possible measure of freedom of movement for developing the world's oil resources without let or hindrance.

Almost all the most spectacular advances in the science of petroleum have been brought about within the past quarter of a century or so, and these amazing achievements justify the expectation that the challenge of the next hundred years can be faced with the utmost confidence.

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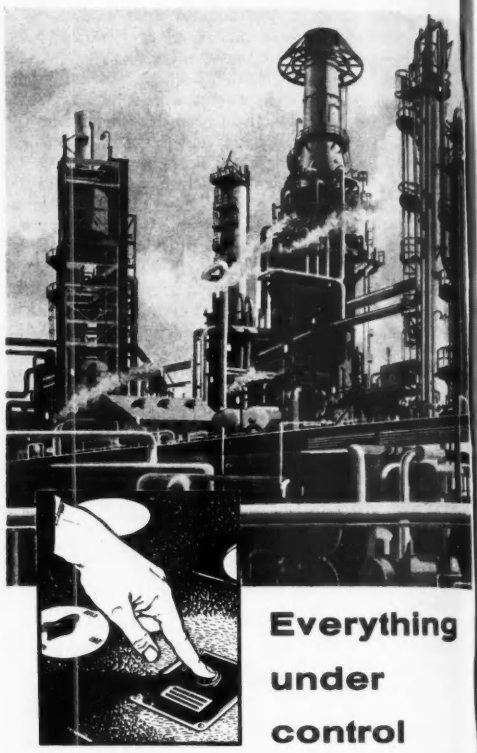

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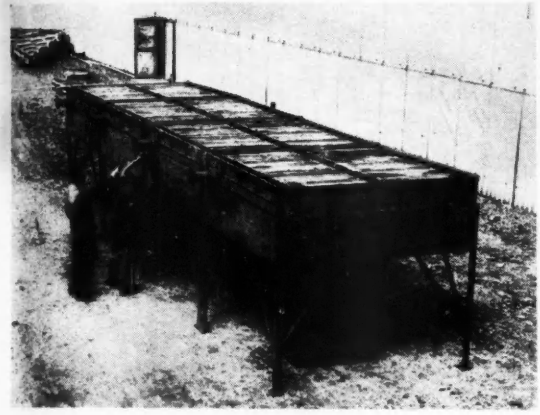

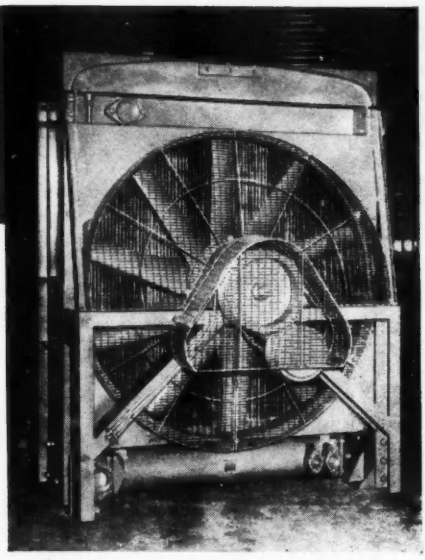

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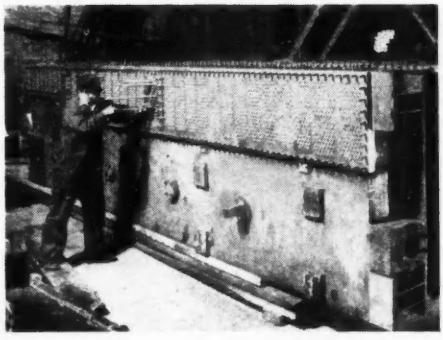

Evaporator for refinery by Procon (Great Britain) Ltd. being tubed with SERCKALBRA Photo by courtesy of Richardson, Westgarth & Co. Ltd.

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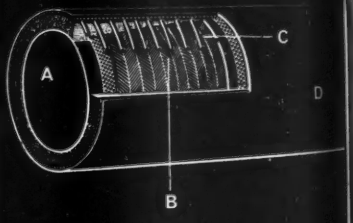

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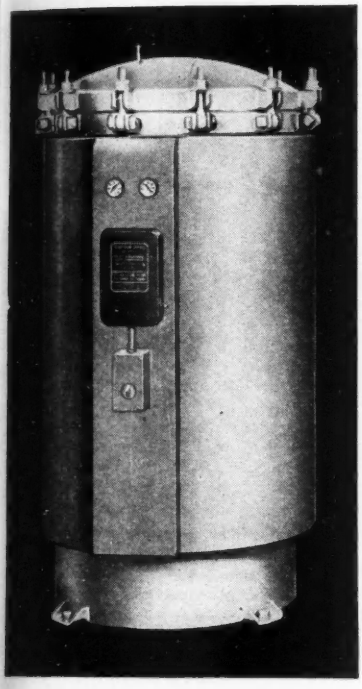

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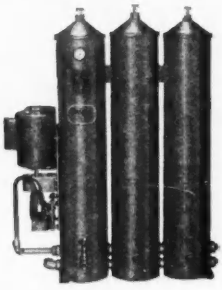

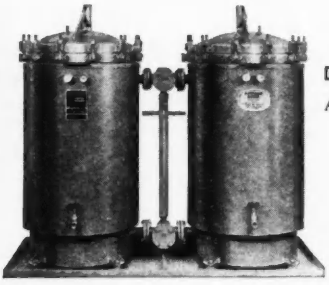

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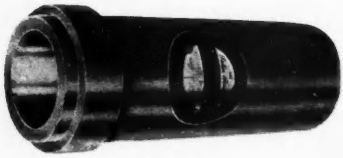

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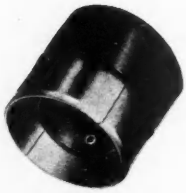

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THE ENGINEERS' DIGEST
REVIEW OF WORLD ENGINEERING PROGRESS
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External Deposits and Corrosion in Boilers and Gas Turbines

By B. A. LANDRY (From *Mechanical Engineering, U.S.A.*, Vol. 81. No. 6, June 1959, pp. 70-73)

FOR particles to collect on the surfaces of boilers or gas-turbine blades, they must first be brought close to the surface itself and be of the proper size. A particle may hit and then rebound from the surface. If it hits or rubs the surface with sufficient force, erosion will result. On the other hand, if the particle is captured physically or chemically by the surface, a deposit is initiated whose growth appears aerodynamically inevitable. Because of high temperatures, reactions can then take place between the various particles deposited and with the gases passing nearby, particularly SO_3 and SO_2. The resulting compounds may then react, by diffusion, with the metal structure on which they are attached and cause corrosion. In boilers, a limit to the growth of the deposit may be reached because of the eventful continuous melting of the outside layer, but the corrosive effect may continue.

Obviously, the study of the causes of deposits, their composition, and their corrosive effects is not simple. Primarily, the impurities in the fuel, the temperatures reached with the combustion system employed, and the aerodynamic behaviour of the gases fixed by boiler or gas-turbine design are the imposed variables subject to varying degrees of control. Additional knowledge is needed regarding the interactions between these variables which cause deposits, particularly on the fundamental nature of these interactions, but the problems are so severe that immediate palliatives deserve attention. These include the removal of certain impurities in fuels, the inhibition of the complete oxidation of sulphur, physical or chemical modification of the metal surfaces, the development of alloys having higher resistance to corrosion, the choice of additive for specific actions, and an answer to the question as to whether to clean gases ahead of economizers or air heaters.

REMOVAL OF FUEL IMPURITIES

The variety of mineral constituents found in fuels is large, and nearly all of them are probably dissociated by the high temperatures of the flame and the combustion chamber. On cooling, certain dissociations persist and recombinations take place, giving rise to chemical species not originally present. The high-temperature chemistry of these reactions is insufficiently known to permit accurate prediction of the nature and extent of these dissociations and recombinations, but it can be inferred that sodium, calcium, silicon, and vanadium oxides may each be released as such, and that they play an important role in initial deposition or in direct corrosive attack.

A most important impurity in nearly all fuels is sulphur. At combustion temperatures, the sulphur compounds dissociate or are oxidized to form SO_2 and SO_3, as also does any free sulphur released. Neither of these anhydrides can react appreciably with hot metals below 1200° F, but they can react with the oxides that may have deposited on metal. The oxidation of SO_2 to SO_3 in the presence of oxygen can be catalysed by hot metals, by active particles in the gas stream, or by active particles after deposition on surfaces. The net result is that the concentration of SO_3 increases as the gases move from burner to economizer. When the temperature is low enough, SO_3 will combine with water to form sulphuric acid, which will attack metal in the cooler areas.

Since it is economically impossible to remove sulphur completely from coal or fuel oil, it is impossible to prevent the formation of SO_2 during combustion. The oxidation of SO_2 to SO_3 seems to require, however, either the presence of atomic oxygen, which can only occur within the flame, or the subsequent intermediary of a catalyst.

Most of the SO_3 produced is probably formed catalytically, and information is needed on the nature of the materials in boilers (including deposits) that may serve as catalysts for the oxidation of SO_2.

Since catalysts may be poisoned or so modified as to be ineffective, better knowledge of the specific catalytic effects present would lead to preventive methods. One approach concerns vanadium compounds which can catalyse the oxidation of SO_2. On the other hand, corrosion caused by vanadium can be prevented by the formation of high-temperature-melting compounds by reaction with suitable additives. If this reaction can be made to occur at a high enough temperature, then the vanadium may lose its catalytic, as well as its corrosive, properties. This dual approach deserves attention.

In the absence of a catalyst, the homogeneous rate of oxidation of SO_2 to SO_3 is low, but may be reduced still further by a reaction inhibitor. Although the concept here is rather hazy, research in this direction would be of fundamental value.

It is still unknown whether the sulphates found in boiler deposits are formed while they are still in the gas stream, or whether sulphate formation is limited to the reaction of SO_3 or SO_2 and oxygen with an initial basic deposit such as Na_2O or CaO. An answer to this problem would represent an important contribution.

Mineral constituents in coal or oil containing chlorine are also dissociated at high temperatures. The free chlorine formed can immediately react with hydrogen to form hydrochloric acid, which attacks metal at relatively low temperatures but which, in co-operation with sulphuric acid, may be quite

corrosive at somewhat higher temperatures. Only one instance has been traced to the chlorine content of the coal in the U.S.A., but many have been reported in Great Britain.

The presence of these impurities in fuels presents several research problems. Fuel preparation can attenuate some of them, but the complete removal of ash and sulphur is not economically feasible. This does not seem to apply, however, to any NaCl that may be present. Fuel oil may contain an appreciable amount of this salt, whose action may be doubly bad, i.e., by promoting vanadium attack through the formation of sodium vanadates, and by promoting low-temperature acid attack because of the formation of HCl.

Until recently, the chlorine content of American coals was not given much attention. Analysis for chlorine is not standard practice, but it would seem desirable to add this determination. Whenever desirable or indicated, the removal of extraneous NaCl from coal by washing should not be technically difficult.

It is not possible to remove vanadium from oil, because it is combined chemically with the oil molecules as an organo-metallic compound. A less costly technique for removing NaCl than washing and centrifuging should, however, be developed. Washing at high pressures and temperatures might not lead to the formation of an emulsion and would not be too costly. Fuel-oil additives to neutralize vanadium could be used simultaneously.

One of the most important and perhaps least understood reactions following combustion is the group of reactions responsible for the combination of various oxides of vanadium with sodium oxide. A number of compounds can be formed, and some of those found in boiler deposits have no correspondent among X-ray diffraction patterns of known sodium vanadates. The synthesising of all possible members of this group and cataloguing their behaviour under X-ray diffraction should be an important fundamental investigation.

Origin of Deposits

The existence of high-temperature deposits is, in itself, something of a mystery. Physically, most of the solid material released from fuel impurities passes through the boiler or turbine. It is claimed that new boilers often have a lengthy period of immunity from deposits. This can mean that, with time, the smooth surface of metals can be altered to increase its ability to hold particles. There is evidence that iron alloys, including steel, can build a microscopic needle structure extending away from the surface; this would be a slow process, but one well worth investigating, as it could point out at least two approaches for correction. One would be a search for alloys not possessing this property, and the other a search for metal coatings that would interfere with or prevent this needle-structure formation.

The other mechanisms of initial deposition which have been suggested, such as the wetting of the metal surface by certain bases or salts, or the formation of surface-potential forces leading to specific attractions, also need exploration. One or more of these approaches might provide an answer as to what makes the particles adhere, but the question still remains as to how they get there in the first place.

The final size of the particle plays an important role when related to the aerodynamic forces operating when the particle is projected towards a surface and must cross the adjacent boundary layer to reach the surface. Further studies are needed to prove what are "favourable" and "unfavourable" size ranges for reaching or not reaching the surface.

Once a deposit has been initiated, a substantial change may occur both in the character of the boundary layer and, if the deposit becomes thick enough, in the aerodynamic behaviour of the gases passing nearby, in certain circumstances leading to rapid growth of the deposit. It would seem that too much emphasis cannot be placed on arriving at the optimum design of boilers or turbines to minimize deposition through the use of appropriate aerodynamic patterns of flow. Model work can help solve design problems and could include studies to show that the admission of secondary (or tertiary) air at certain critical spots might go far in alleviating the situation.

Prevention of Corrosion

If deposition is unavoidable, the question arises as to whether the corrosive effects of deposits can be reduced by appropriate selection of metal surfaces. In this connection, it is true that the field of development of new alloys is so large that there is every assurance that alloys with suitable mechanical properties and corrosion resistance can be found. The challenge is, however, one of cost, though the chances are good, particularly for structural members that are not water- or air-cooled.

A promising method of conferring corrosion resistance is by surface coating. This has not been successful so far, in boiler or turbine applications, but, with the variety of techniques and types available, it would be surprising if none proved successful.

One aspect of the metallurgical problems associated with deposits and corrosion that must be kept in mind is that of the compatibility of fuel additives with the metals with which they may come in contact. Because boilers and turbines are normally poor ash collectors, there has been little hesitancy in the use of additives to combat specific nuisances such as vanadium compounds and SO_3, because the boiler and turbine can be relied upon not to retain too much of the additive. However, this has not always been true, and certain additives, while reducing corrosion effects, have added to deposit problems. Special attention should be given to the complete behaviour of additives, so as not to solve one problem at the expense of another.

Although the specific effect of additives seems to have been well explored, further research should probably be done. An important aspect is the method by which they are added to the fuel. For gas turbines, a possible but perhaps costly approach is the development of oil-soluble additives for reaction with vanadium. Water-soluble additives should not be overlooked if they can be shown to be equally effective. The presence of a certain amount of water solution in the fuel oil supplied to a gas turbine is beneficial to the cycle if this water does not interfere

(Concluded on page 330)

Photo-Resistors of Compressed and Sintered Cadmium Sulphide

By N. A. DE GIER, W. VAN GOOL, and J. G. VAN SANTEN. (From *Philips Technical Review*, Vol. 20, No. 10, 1958/59, pp. 277-287, 17 illustrations)

SELENIUM photo-resistors have never found large-scale applications, such devices as germanium point-contact diodes and germanium photo-transistors having proved to be more useful. Because their sensitive surfaces have a very small area, their sensitivity in terms of metre-candles, i.e., their lux sensitivity expressed in amperes/lux, is on the low side. However, they have a high lumen sensitivity, i.e., lux sensitivity divided by the area [m^2] of the sensitive surface of the cell or resistor.

Consider a crystal having the shape of a rectangular slab of thickness t, width l, and length d, the area exposed to radiation being ld. Then, if a voltage is applied to two electrodes of suitable material, fixed to the cadmium sulphide crystal and separated by a distance d, electrons will be able to enter the crystal from the cathode and to leave it by way of the anode. Thus, a current can flow permanently, and the crystal can constitute a practical photo-transistor of high sensitivity, provided that the distance d between the electrodes is kept small and that $\mu\tau$ has a high value, where μ is the factor of proportionality or mobility of the electrons and is the mean life of a free electron, i.e., the average time elapsing before an electron is recaptured by an ion or atom that has lost one of its own electrons. The lumen sensitivity will be independent of the area ld exposed to light, so that the lux sensitivity will be exactly proportional to this area. Also, the current will increase in direct proportion to the applied voltage, so that, for the highest possible sensitivity, the voltage across the crystal should be high.

Although it has been known for many years that it is possible to find in a group of cadmium sulphide crystals individuals exhibiting exceptionally high photo-sensitivity, the use of this compound for the large-scale production of photo-resistors has only lately become a practical proposition. Recent research carried out on cadmium sulphide and related compounds, e.g., cadmium selenide and cadmium telluride, has established that photo-conductivity does not occur in cadmium sulphide unless certain impurities, known as activators, are present, while still other impurities act as inhibitors. Activators include copper, silver, chlorine, and gallium. Iron is an inhibitor and must not be present in concentrations higher than one atom per million cadmium atoms.

It will thus be appreciated that it is not only necessary to produce cadmium sulphide crystals in which suitable impurities are present, but also to do so in such a way as to allow the concentrations of the activators to be conveniently controlled. Such a process has now been developed, in which a precipitate of cadmium sulphide is first prepared by passing hydrogen sulphide through a solution of a cadmium salt, providing very pure cadmium sulphide in the form of an extremely fine powder, with a grain size of 0·1 micron or less. To this powder are added the activators (copper and gallium in the case of the particular photo-resistors discussed in this article), and the powder is then subjected to a temperature between 700° C and 900° C. This heat treatment, which lasts several hours, results in the formation of much larger grains (10 to 100 microns), in which the added activating material is uniformly distributed and in which a high degree of photo-sensitivity is exhibited.

To produce a homogeneous coherent material from this powder, with a photo-sensitivity little inferior to that of the grains, the process developed by Philips has proved quite practicable for compressing the powder into tablets without using a binder. The filling factor of the compressed powder is approximately 90%, which is a very high figure compared with other substances and which can only be explained by the fact that the grains are to some extent plastic. The pressing operation gives rise to imperfections in the crystal lattice, and these tend to reduce the photo-sensitivity of the material very considerably. However, unlike the inhibiting impurities, the lattice imperfections can be considerably reduced or modified, this being effected by a second heat treatment. Careful consideration must be given to the temperature to which the compressed powder is to be heated, the duration of the treatment, and the atmosphere in which it is carried out. In the course of this treatment, the grains coagulate in such a way that finally a material is obtained which is fairly strong mechanically, besides possessing a high degree of photo-sensitivity. However, it is still possible to recognize the grains in the structure of the material, as shown in Fig. 1.

Heat treatment enhances the photo-sensitivity of the material, partly because it largely removes the lattice irregularities and partly because it improves contact between the grains. The dark resistance, which is less dependent on the intergranular contact resistance, is not seriously affected by the heat treatment. Needless to say, the chance of impurities

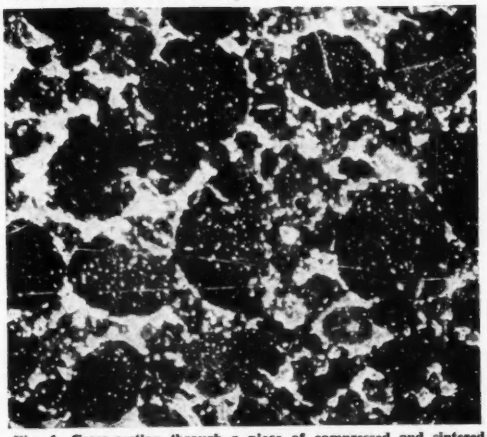

Fig. 1. Cross-section through a piece of compressed and sintered cadmium sulphide. (x150)

being introduced into the material in the press must be carefully guarded against. The risk of contamination is reduced to a minimum by making the punch and die of suitable material and by giving them a particularly fine finish.

If the properties of the material produced in this manner are compared with those of one in which coherence has been obtained by adding a binder, a striking difference is found in regard to photo-conductivity, i.e., the effective value of $\mu\tau$ is considerably greater for the compressed and sintered material than for the other kind.

Insofar as the dosage of additives is concerned, it has been found that there must be a very definite constant ratio between the copper and gallium concentrations. Thus, too much copper reduces the photo-sensitivity of the material, while a relatively high concentration of gallium results in a low dark resistance. The higher the concentrations in which additives are present, the more serious are the effects of departures from the correct proportions. On the other hand, it is desirable to add activators in fairly high concentrations, so that these may be large in comparison with those of the impurities already present, and this is the only way of making sure of obtaining a product whose properties are reasonably constant. All in all, there is not much freedom with regard to the choice of these concentrations.

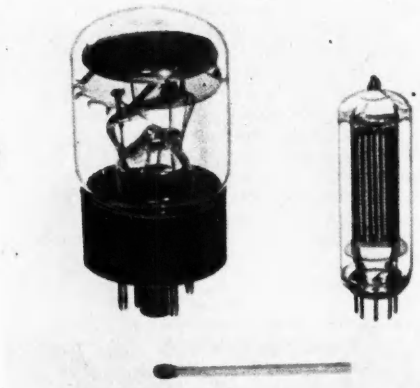

Fig. 2. **Two cadmium sulphide photo-resistors, showing (left) a type with the plate perpendicular to the tube axis, and (right) a type with the plate parallel to the tube axis.**

Fig. 2 shows two Philips photo-resistors made of compressed and sintered cadmium sulphide, both consisting of a glass envelope (for protecting the contents), in which is a plate of photo-conductive material, 0·8 mm in thickness. Metal-film electrodes, in the form of two interlocking combs, as shown in Fig. 3, are coated on one side of the plate, the use of electrodes of this shape satisfying two conditions for high sensitivity, i.e., a large sensitivity area and a small distance between the electrodes. The "teeth" of the combs are 1 mm apart, and the electrodes are formed on the plate by applying a mask to it and depositing a suitable material, e.g., copper, silver, aluminium, or gold, evaporated in a vacuum. The sensitivity of these resistors increases with the voltage across them, as already stated, and the highest voltage permissible is determined by the clearance between the electrodes. It should be noted that, in the type of photo-resistor shown at the right of Figs. 2 and 3, the cadmium sulphide plate is mounted parallel to the axis of the tube, whereas the plate in the type at the left of Figs. 2 and 3 is perpendicular to the tube axis, the latter type being designed to respond to light coming from above the tube, and the former to light coming from the side.

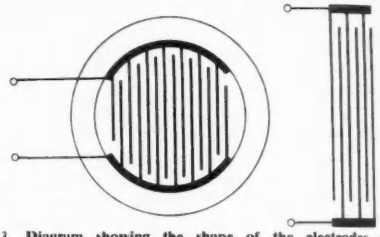

Fig. 3. **Diagram showing the shape of the electrodes of the photo-resistors illustrated in Fig. 2.**

Measurements have provided information concerning the properties of the sensitivity layer in these photo-resistors. Thus, with regard to sensitivity, the value of $\mu\tau$ has been found to average 0·5 cm²/V, while their spectral sensitivity is such that they are sensitive throughout almost the whole of the visible range and an appreciable way into the infra-red band, the sensitivity peak occurring at about 6800 angstroms, as shown in Fig. 4.

Insofar as their current/voltage relation is concerned, variation in current through these resistors with applied voltage is roughly linear, the voltage exponent being between 1·05 and 1·10, implying that Ohm's law is approximately obeyed, as distinct from materials containing a binder, where the current through these varies with a voltage exponent between 3 and 4. The relation between current and intensity of illumination (Fig. 5) is also roughly linear, the exponent being about 0·85.

Temperature exercises very little effect on these resistors, a rise from 0 to 40° C causing the current to fall off by only 10%. In this respect, the performance of cadmium sulphide photo-resistors is particularly good, compared with that of other types.

With respect to speed of response, these resistors

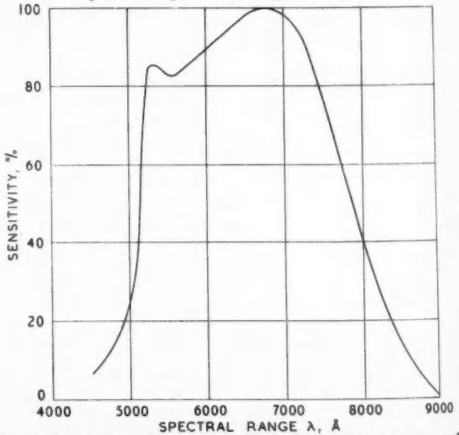

Fig. 4. **Spectral sensitivity of photo-resistors made of compressed and sintered cadmium sulphide.**

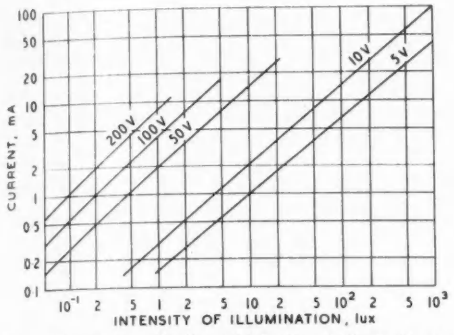

Fig. 5. **Current as a function of intensity of illumination for different voltages applied to a cadmium sulphide photo-resistor.**

are unable to follow rapid changes in the intensity of illumination. However, the more intense is the illumination, the more quickly they react. Thus, after the tube has been exposed to 100 lux, the current decays to half-strength within 5 milliseconds, whereas, after exposure to 0·1 lux, the current takes 0·25 second to decay to its half-value. Finally, it should be mentioned that the dark resistance of the tube shown at the left of Figs. 2 and 3 exceeds 10^7 ohms, while that of the tube at the right exceeds 10^8 ohms.

Applications of Cadmium Sulphide Photo-Resistors

Vacuum and gas-filled photo-cells can usefully be replaced by cadmium sulphide photo-resistors in any application where sensitivity is important but speed of response is less so. The great advantage of cadmium sulphide photo-resistors in such applications is that they can be connected directly to a relay, amplifiers and thyratrons being unnecessary, with considerable simplifications in the resulting circuitry.

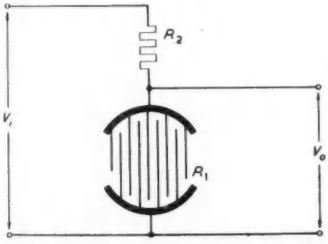

Fig. 6. **Crackle-free potentiometer circuit using a cadmium sulphide photo-resistor.**

Such applications of the cadmium sulphide photo-resistor are not new in principle, but there exists a further group of applications in which they are specially suitable and cannot be replaced by vacuum or other types of photo-cell. An example of an entirely new application is the "crackle-free" potentiometer. Most potentiometers in common use are resistors with a movable tapping, and the changes in output voltage resulting from movement of the sliding contact are not completely continuous, giving rise to objectionable crackling when the slide is in motion. However, a crackle-free potentiometer circuit (Fig. 6) can be made by putting a fixed resistor R_2 in series with a cadmium sulphide photo-resistor R_1 so that, with a given input voltage V_i changes in the luminous flux incident on R_1 cause its resistance and hence the output voltage V_o across its electrodes to change. The luminous flux can be altered by varying the current flowing through the filament of an incandescent lamp, the thermal inertia of the filament precluding abrupt changes in light emission, so that no crackling occurs; alternatively, the intensity of illumination can be regulated mechanically, e.g., by means of one or two diaphragms mounted close together. Such a crackle-free potentiometer, suitable for satisfying the requirements of the volume control of a conventional radio receiver, can be obtained by combining a cadmium sulphide photo-resistor having a dark resistance of at least 10^7 ohms with a fixed resistor R_2 having a value of about 2×10^6 ohms. A satisfactory unit of this type for radio or television sets can easily be made in compact form by combining a small cadmium sulphide photo-resistor with a miniature 6·3-V electric lamp, the entire unit being enclosed in a light-tight tube to obviate interference from any other light in the vicinity.

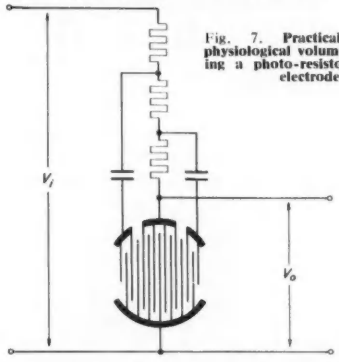

Fig. 7. **Practical form of physiological volume control using a photo-resistor with four electrodes.**

By making cadmium sulphide photo-resistors with more than two electrodes, it is possible to design circuits giving so-called physiological volume control, with which, when its output voltage is small, low-frequency sounds are attenuated to a smaller extent than high-frequency sounds, stopping them from becoming inaudible before the high-frequency sounds with decreasing output voltage. A practical form of physiological volume control, using a photo-resistor with four electrodes, is shown schematically in Fig. 7.

In applications of this type, alternating current is used for supplying the lamp, and it may well be asked whether difficulties may not arise in this connection. It is true that the luminous flux can be expected to show some fluctuation (at double the mains frequency) and that the voltage from the output of the photo-resistor potentiometer will exhibit corresponding amplitude variations. It has, however, been found that the 100-cps modulation of the sound signal is inaudible, provided that its depth does not exceed 3%. In fact, the results of measurements show that, for the normal resistance values of a photo-resistor of the type shown in Fig. 7, the modulation depth will be very much less than 3%, being 0·1% at 150,000 ohms and 0·3% at 50,000 ohms. Consequently, the ripple is normally quite

inaudible, and only when the resistance of the cell (and hence the voltage across it) is very low is the 3% limit slightly exceeded.

Potentiometers embodying cadmium sulphide resistors have advantages over and above freedom from crackle. Thus, there is no need for the control rheostat to be mounted in the immediate vicinity of the photo-resistor and lamp, so that each can be given a location which is most convenient. In the case of a volume control for a radio receiver, the potentiometer unit can, for instance, be placed close to the detector diode, with the control rheostat in a position that is in easy reach of the listener. The rheostat can even be mounted in a separate box

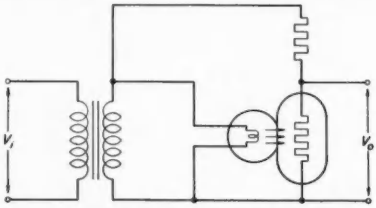

Fig. 8. **Circuit incorporating a cadmium sulphide photo-resistor for statbilizing an alternating voltage.**

connected to the set by a cable, thus providing a simple means of remote control, which can also be adapted easily for adjustment of brightness and contrast in television sets and for volume control in stereophonic sound reproduction.

A third application of the cadmium sulphide photo-resistor is in a simple circuit for stabilizing an alternating voltage. The secondary of the transformer in this circuit (Fig. 8) supplies both a potentiometer chain, of which the photo-resistor forms part, and a small exciter lamp. If the voltage across the secondary should rise on account of an increase in the input voltage, the lamp will shine more brightly, so lowering the resistance of the photo-resistor and reducing the proportion of the secondary voltage appearing at the output. With suitable resistance values, increases in the secondary voltage can be exactly compensated by the decrease in the output voltage. Over a large range of input voltages V_i, the output voltage V_o shows very little variation when no current is taken, varying between 2·15 V for a V_i value of 80 V and 2·51 V for a V_i value of 260 V.

Other possible applications, some of which are not new, except in the sense that the use of cadmium sulphide photo-resistors simplifies the circuitry, include their use in fire-alarm systems, in which they are particularly suitable, as they exhibit maximum sensitivity to red light and are sensitive to infra-red light with wavelengths up to 0·9 micron. They can also be employed for the detection of smoke, for switching street-lighting on and off automatically, for automatic dimming of motor-car headlamps, and for automatic adaptation of contrast and brightness in television receivers to room-lighting level. It should also be noted that, in those particular applications requiring some system to be switched on or off, it is not always necessary to make the photo-resistor control a relay, as in some cases the cell itself can be used as a switch.

In conclusion, it may be said that cadmium sulphide photo-resistors have already found application in a number of fields and that they should also prove to be useful in others, by virtue of their high sensitivity to light, their low supply voltage, their high load capacity, and their sensitivity to temperature changes.

External Deposits and Corrosion in Boilers and Gas Turbines

(Concluded from page 326)

with pumping, atomization, and combustion. This is not true of boiler-fired systems, but better distribution of the additive might be achieved in this way, at a slight thermal loss. Insofar as the introduction of fine solid additives into the gas stream of boiler furnaces is concerned, applied research will probably be required to smooth out this operation.

The removal of acids from the gases, before metals are damaged, can occur either by adsorption within the pores or interstices of otherwise inert dust particles, as often happens in pulverized-coal firing, or by neutralizing the acid by reaction with a basic particle. If the coal does not produce enough fine particles having adsorptive properties, then the use of a neutralizing rather than an adsorptive additive seems indicated, because of lower cost owing to lower tonnage requirements. Evaluations of available adsorptive and reactive materials in a given locality and of methods of application should be made.

Adsorptive material to remove the acid from the gases before the metal of the air heater is attacked is sometimes provided naturally, and sometimes by an additive. There are two other possible solutions to the problem of acid attack, both of which have the advantage that no additive is needed. One solution is to develop an inhibited metal surface which resists acid attack while not interfering markedly with heat transfer. It is known that iron compounds can receive this inhibiting treatment, but it is still an open question whether it can be applied to air heaters.

The other approach, which deserves thorough study, is based on the theory that the presence of a porous deposit on air-heater metal tends to make the temperature of the metal more nearly that of the air being heated than that of the gases supplying the heat. Therefore, acid fumes which have not reached the dew point while mixed in the gases can reach it when they have diffused through the deposit to the metal. Corrosion then occurs. Under this theory, it would be advisable to remove all or nearly all of the solids ahead of the air heater or even the economizer. With no solid deposit, there would be little or no corrosion.

Finally, it should be pointed out that the correlation between the determinations of the sulphuric acid concentration in gases by dew-point methods and by chemical methods is not good. Many of the results obtained in studying corrosion are not comparable, because dew-point determinations were used to measure acid concentration, though the fault may lie in using inaccurate dew-point meters. If various hydrates of SO_3 can exist, however, the chemical method may not differentiate between them, whereas their corrosive effect may be different. Fundamental research in this area is strongly indicated.

The Elastic Properties of Twisted Tubular Pressure Elements

By L. A. Foigel, Z. Kh. Shekhter, and S. V. Elyukim. (From *Priborostroyeniye*, No. 4, 1959, pp. 15–17, 11 illustrations)

In Russia, increasing use is being made of sensitive elements for measuring pressure in the form of twisted tubes, of the type shown in Fig. 1, and this paper describes the results of tests carried out to determine certain elastic properties of these elements as a function of their wall thickness and pitch of twist. In all these tests, the profile of the elements, which were constructed of stainless steel, was similar to that shown in Fig. 2, the length, including the flanged nipple, being 78 mm.

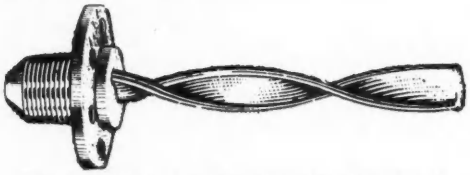

Fig. 1. **Twisted tubular-type pressure element with flanged nipple.**

For the purpose of this investigation, thickness δ is taken as the average thickness determined by weighing, 0·01 mm corresponding approximately to 0·1 gram. Non-uniformity of wall thickness has not been taken into account. Pitch h was calculated from measurements of the angle between two transverse cross-sections, one of which coincided with the upper end of the element, and the other 10 mm away from the lower end. The reason for choosing an intermediate section was that the lower end of the element was rounded, so that it was impossible to tell exactly where the twist ended. Pitch h was then calculated from the equation

$$h=360H/\phi_o \quad \ldots \quad \ldots \quad (1)$$

where H is the distance between the cross-sections and ϕ_o is the angle between them. The value of pitch h determined in this way is the mean pitch over an arbitrarily selected portion of the element, measuring accuracy being of the order of 2 mm.

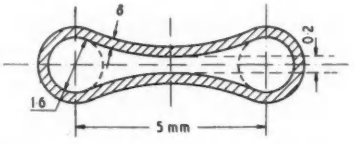

Fig. 2. **Profile of twisted-type tubular pressure element.**

Sensitivity α is understood to mean the relation of the angle of untwisting ϕ to the pressure P [kg/cm²] being measured, i.e.,

$$\alpha=\phi/P \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Pressure P was measured with a precision pressure-gauge, while the angle of untwisting ϕ was determined from measurements with a microscope of the linear displacement of the end of a pointer attached to the upper end of the element. For calculating the angle of untwisting ϕ, a correction had to be made, inasmuch as the end of the pointer moved along an arc, while measurements were effected along the chord. This correction, in the case of angles up to 10 deg., is, however, small and, by selecting an appropriate pointer length, practically any degree of accuracy can be attained. Actually, the length of the pointer used was 57·3 mm, so that 1 mm corresponds to 1 deg., the measuring accuracy being 0·01 deg.

With this equipment, which was also used for measuring the hysteresis and non-linearity of characteristic curves, tests were made on more than 100 experimental and batch-produced elements of varying pitch h and thickness δ (i.e., δ=0·23, 0·37, 0·39, 0·43, 0·56, and 0·64 mm). Figs. 3 and 4 illustrate the relation between sensitivity α and pitch h with δ-values of 0·23 and 0·64 mm respectively, though the curves obtained with all values of δ are basically of the same type, with sensitivity α reaching a maximum value at a certain pitch h. The scatter of the test points shows the degree of accuracy obtained and is slightly in excess of the possible error in measuring pressure P or angle of untwisting ϕ, most probably because of non-uniformity of wall thickness and of longitudinal pitch, and also because of some minor variations in the shape of the element.

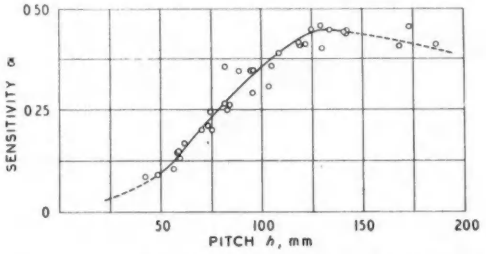

Fig. 3. **Sensitivity α as a function of pitch h for a thickness δ of 0·23 mm.**

It should be noted that all these curves of sensitivity α as a function of pitch h for different values of thickness δ are direct plots of the experimental results, from which the other graphs required for analysis and production tests were plotted by interpolation. However, other graphs are of even greater significance, i.e., the curves of sensitivity α as a function of the reciprocal of pitch $1/h$ for different values of thickness δ (Figs. 5 and 6), and the curves of thickness δ as a function of pitch h for different values of pressure P (Fig. 7), the curves in Figs. 5 and 6 being required for analysis of the non-linearity of the characteristic curves of the elements, and those in Fig. 7 for production tests on current batch-produced elements. It should be noted that the curves in Fig. 7 correspond to that value of sensitivity α at which the angle of untwisting ϕ is 12 deg. at a maximum value

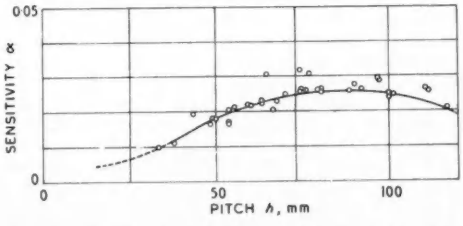

Fig. 4. **Sensitivity α as a function of pitch h for a thickness δ of 0·64 mm.**

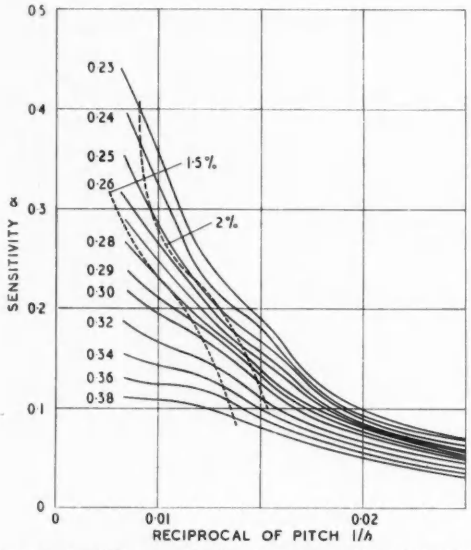

Fig. 5. Sensitivity α as a function of the reciprocal of pitch $1/h$ for thickness values δ between 0·23 and 0·38 mm.

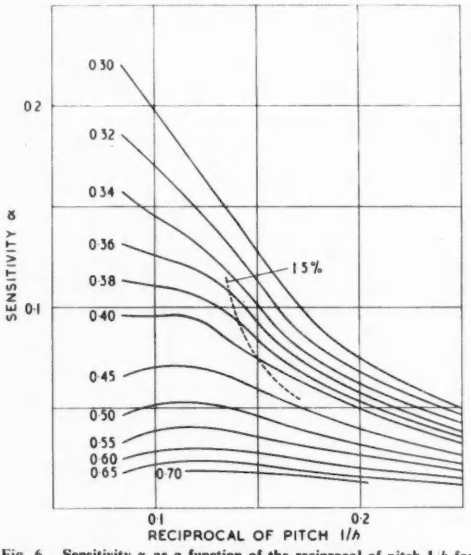

Fig. 6. Sensitivity α as a function of the reciprocal of pitch $1/h$ for thickness values δ between 0·30 and 0·70 mm.

of pressure P below 150 kg/cm² or 8 deg. at a maximum pressure P above 150 kg/cm².

Two curves are plotted in Fig. 7 for each value of maximum pressure P, and these define the sensitivity tolerance (in this case, $\pm 10\%$). The accuracy of these curves has been established from data collected as a result of continuous inspection of elements which were batch-produced over a period of several months. From these data, it appears that the mean deviation in the angle of untwisting ϕ, averaged over all batches, amounts to 1·5 deg. for low-pressure elements and 0·8 deg. for high-pressure elements, the scatter in an

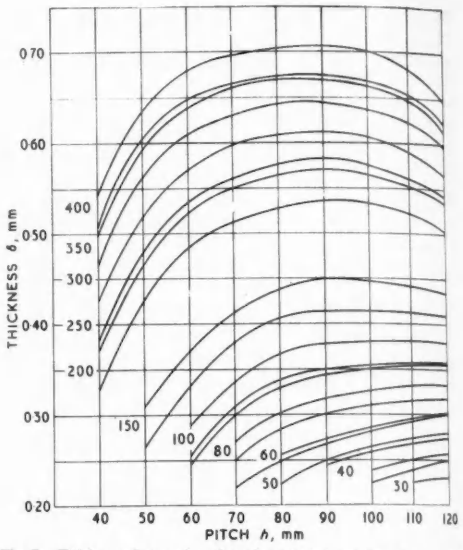

Fig. 7. Thickness δ as a function of pitch h for different values of pressure P.

individual batch amounting to about 0·6 and 0·4 deg, respectively. The curves indicate a mean deviation in the angle of untwisting ϕ of 1·4 deg. for low-pressure elements and 0·7 deg. for high-pressure elements, and these values include such purely manufacturing errors as those incurred from weighing, tool wear, etc. Any further increase in accuracy depends on the solution of certain production problems with a view to producing elements which are more uniform with regard to their geometry.

Generally speaking, the characteristic curve of an element is non-linear. Not all the reasons for this are known, but certainly the principal reason is the dependence of sensitivity α on pitch h. In fact, when the element untwists, its shape is altered and, in particular, pitch is changed as a result of the relative rotation of the cross-sections involved. However, by making certain simplifying assumptions, the magnitude of the non-linearity can be computed. Thus, taking the deviation Δ of the characteristic curve from linearity as

$$\Delta = (0{\cdot}5 - (\phi_{0{\cdot}5}/\phi_{1{\cdot}0}))\ 100\ [\%] \quad \ldots \quad (3)$$

where $\phi_{1\cdot0}$ is the angle of untwisting at maximum pressure and $\phi_{0\cdot5}$ is the angle of untwisting at half the maximum pressure, it is possible to obtain the value of Δ for a working pressure P as

$$\Delta = \frac{P}{14{\cdot}4H} \times \frac{\mathrm{d}\alpha}{\mathrm{d}(1/h)} \quad \ldots \quad \ldots \quad (4)$$

the differentiation being carried out graphically from the curves of sensitivity α as a function of the reciprocal of pitch $1/h$ in Figs. 5 and 6, in which the dotted curves correspond to a non-linearity of 2% and/or 1·5%. Comparisons with the actual test results have established that non-linearity in elements from the same batch is different, non-linearity apparently being affected by further, as yet obscure, causes. However, comparisons of theoretical estimates of non-linearity based on eq. (4), with those actually noted in tests on a fairly large batch of elements show satisfactory agreement.

Plasma-Energy Transfer in Gas-Shielded Welding Arcs

By H. C. Ludwig. (From *The Welding Journal*, Vol. 38, No. 7, July 1959, pp. 296s–300s, 9 illustrations)

The self-magnetic field generated by high-current arcs in gas-shielded welding processes can become the most important factor contributing to the forces which promote the transfer of electrode metal through the arc. The magnetic force is one of compression, acting on the current-carrying members of the welding electrical circuit, including solid conductors, the sessile molten drop at the tip of the electrode, and the arc plasma. To detach a metal drop from the electrode, a force must be applied which exceeds the surface tension of the metal drop in the sessile configuration. A magnetic force great enough to compress or pinch the arc plasma must exceed the force exerted by the thermally expanding gas. The interaction of these forces is considered as the major parameter controlling the geometric form of the arc discharge and the characteristics of metal transfer.

A pronounced improvement in the uniformity of metal transfer came with the development of the argon-gas-shielded consumable-electrode process. By adjustment of conditions which determine the density of current conducted through the argon-shielded arc, the metal-drop rate can be controlled over a wide range without introducing metal spatter. The self-magnetic field, a function of current density, which acts on the arc plasma, is influenced by the transport properties of the gas composing the plasma, and it should be noted that the self-magnetic field can also act on the conducting electrode in the solid and liquid state.

As the attained temperatures and degree of thermal ionization are increased, the effects of neutral molecules and atoms contained in the arc plasma are lessened because of a decrease in their number density. On the other hand, there is a proportionate increase in the number density of ions and electrons, which take on the character of the transport properties of the plasma as the temperature rises. Moreover, the coupling of ions and free electrons to the self-magnetic field introduces gradients in pressure. These gradients, which produce acceleration of the particles, cause streaming towards either terminal of the arc. The transformation of the input energy in arcs is controlled irreversibly by the intensity and distribution of these forces and fluxes as influenced by the composition of the arc plasma.

Plasma Composition

In the case of hydrogen, nitrogen, and carbon dioxide, molecular dissociation is essentially complete at 10,000° K. In following the course of dissociation and thermal ionization with temperature, it will be appreciated that, with increasing temperature, molecular dissociation may take place, as in the case of nitrogen, and excitation and ionization may proceed. Thus, for instance, the density of singly ionized atoms of nitrogen increases with temperature and reaches a maximum, while the density of neutral atoms decreases. An increase in the density of doubly ionized particles follows, with further ionization occurring at higher temperatures. In the case of nitrogen and argon, the maximum occurs at approximately 17,000° K, and at 26,000° K for helium. Each stage of ionization contributes to the number of free electrons.

Arc-Energy Transfer

The electrical energy is changed in the arc into other forms of energy. An understanding of the details of these changes provides information about the thermal conductivity of the arc plasma. The usefulness of an arc as a joining tool is very largely determined by the manner in which the electrical energy is transformed into heat energy; however, other forms of energy may extend this utility.

The heat energy in an arc is transferred by the mechanisms of conduction, convection, diffusion, and radiation, all of which are influenced to some extent by the development of a magnetic field, another form of energy. In the analysis of the arc energy, a division can be made into that portion which moves axially, governed primarily by Ohm's law, and that portion which moves radially, accounting for the deviation in electrical conductivity from Ohm's law. The irreversible process of energy transformation produces forces and fluxes which incite the movement of plasma particles and energy. Account is made for the total of these quantities in the magnitude of the plasma-field strength.

Conduction takes place by means of interparticle transfer from a region of higher temperature, called the source, to a region of lower temperature, called the sink. Radiation requires no medium at all and travels in waves. Convection of the natural type is driven by the force of gravity and depends on the difference in mass density of the heated gas and the main body of surrounding gas. Diffusion, which can take place via molecules, atoms, ions, and electrons, depends both on concentration and thermal gradients.

It is possible to make calculations to account for the contribution of heat transfer due to the recombination of atoms to molecules if the diffusion coefficient differs from that of normal atoms. As the temperature increases, the contribution due to electrons becomes greater and therefore, through classical electron conduction, assumes the important role of thermal conductivity.

Thermal Conductivity

From the composition of plasma gases and the development of thermal velocities and effective cross-sections by kinetic energy, it is possible, based on the results of various investigators, to determine the total thermal conductivity of gases by adding the contributions due to molecules, atoms, ions, and electrons.

The total thermal conductivity of several gases has been determined, the coefficients for hydrogen, helium, nitrogen, and argon, as derived by various investigators, being shown in Fig. 1, in which a general increase in thermal conductivity with temperature will be noted in the case of all these gases, while the contributions of the molecular dissociation-diffusion-association mechanism in the diatomic gases, hydrogen and nitrogen, can readily be observed. In the following, an attempt will be made to show how the plasma transport property of

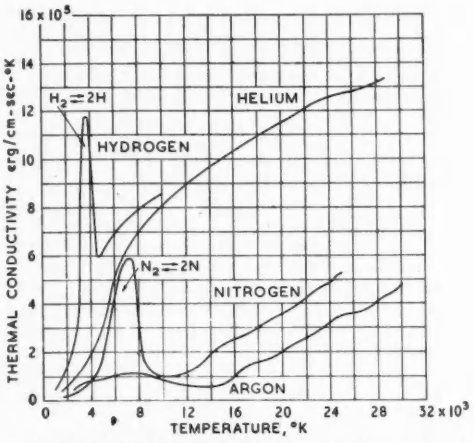

Fig. 1. Calculated total thermal conductivity of hydrogen, helium, nitrogen, and argon as a function of temperature.

thermal conductivity influences the geometric shape of the arc discharge in argon and helium.

Nature of High-Current-Density Arcs

Experimental evidence shows that thermal conduction influences the geometric shape of the arc discharge. As an illustration, a comparison is made of the geometric forms of arc plasma due to low- and high-thermal-conductivity gases, argon and helium respectively, a series of accurately reproduced illustrations of arcs burning in argon-helium gas mixtures being shown in Fig. 2. It will be noted that addition of helium to the argon arc causes the plasma to be altered gradually from a truncated cone to a spherical form. For the arcs shown in Fig. 2, a tungsten electrode was used, and the arcs were all maintained at a drawn current of 100 A. The corresponding variation in the plasma gradient (field strength) with plasma composition is shown in Fig. 3, indicating a considerably higher power consumption for the helium arc than for the argon arc. The higher potential across the helium arc also indicates that higher temperatures are necessary and that more energy is being dissipated to maintain the discharge.

Measurements of the radial temperature of an argon-tungsten arc by spectroscopic means show that temperatures in the arc axis attain values of the order of 16,000° K, with the temperature falling to 10,000° K near the arc boundary. A limited survey of the temperature distribution in the helium arc indicates an axial temperature of 27,500° K.

If the thermal conductivity of a gas is very high, the plasma will be isothermal to a rough approximation. This, in other words, means that the temperature gradient of a helium plasma will be significantly less than that for the argon plasma. Also, the mean temperature for any given horizontal plane of the helium arc will be greater than that for a corresponding argon plasma, because of both the higher axial temperature and lower temperature gradient. In a given volume, the thermal gas pressure for the helium arc will be higher than that for argon, according to the ideal-gas law.

The interaction between the arc-plasma kinetic pressure and the self-magnetic field pressure is a very important factor in the physical characteristics of the arc as the current conducted becomes high. The amount of conducted current required to make this interaction significant varies with the gas making up the arc plasma. The self-magnetic field effect of "pinch," the force tending to reduce the cross-section of a conductor, has been observed in mercury-vapour, xenon, argon, and carbon arcs. A streaming of the plasma particles which occurs away from the plasma zone of smallest cross-section and of highest pressure has been observed with measured velocities as high as 300 m/sec., i.e., approaching the speed of sound, and with developed forces of the order of 1000 dynes. The axial gradient in pressure introduced by the compressive force of the magnetic field produces the streaming motion which transfers metal through the arc.

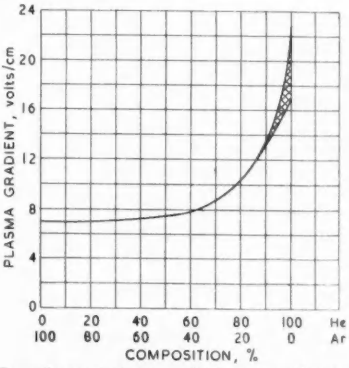

Fig. 3. Dependence of plasma gradient on percentage composition by volume of argon-helium shielded arcs.

The plasma pressure must be balanced by the combined magnetic pressure and atmospheric pressure. The effects of convection, conduction, diffusion, and radiation mechanisms contributing to the attained temperature of the arc plasma and temperature gradient should appear in a rigorous energy-balance equation. An analogy in pressure balance may be found in the equilibrium of pressure inside and outside a soap bubble or balloon, where atmospheric pressure and the pressure exerted by the bubble or balloon wall confine the gas. The arc

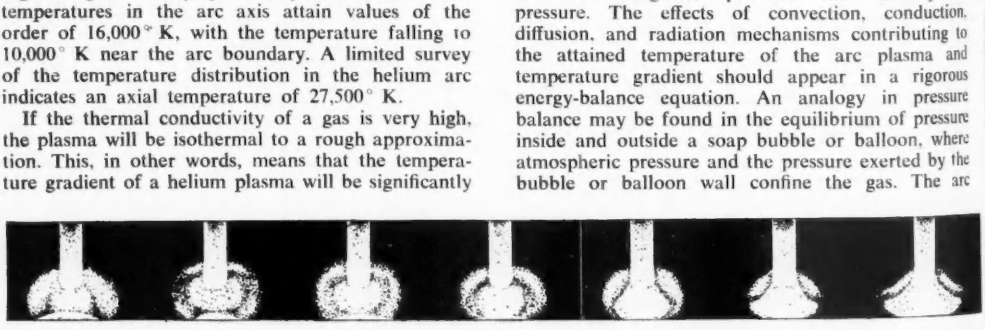

Fig. 2. Dependence of arc-plasma shape on percentage composition by volume of argon-helium shielded arcs.

plasma may also contain an axial gradient in pressure. This is analogous with the difference in pressure produced when a break or opening is made in the bubble or balloon.

The pressure of the gas varies as a function of the temperature distribution, and gases which attain a higher temperature and a lower temperature gradient will attain a higher pressure for a constant volume. The determination of the radial plasma pressure gradient which exists with a radial temperature gradient is mathematically complicated, but, if equilibrium is assumed between the plasma pressure and the magnetic pressure, it can be calculated by determination of the self-magnetic field pressure. Since the kinetic pressure of a gas for a given volume is greater for a higher temperature, the gas expands until the equilibrium with opposing pressures is attained. Because of both the higher axial temperature and lower temperature gradient, helium-tungsten arcs are more difficult to "pinch," requiring a higher magnetic force. A higher magnetic force may be obtained by increasing the drawn-arc current, since the magnetic force varies as the square of the current. A threshold appears with the helium-tungsten arc at a current of about 150 A, where the shape of the arc changes from a sphere to a truncated cone, as shown in Fig. 2. With a consumable steel electrode, 1/16in. in diameter, the threshold of discernible pinch occurs at 470 A reverse polarity The threshold for other gases still remains to be determined.

GERMANY

Continuous Magnetic Testing of Electrical Sheet

By D. Stäblein. (From *Technische Mitteilungen Krupp*, Vol. 17, No. 2, May 1959, pp. 90-94, 3 illustrations)

The use of cold-rolled, instead of hot-rolled, magnetic sheet as a material for electrical equipment makes it desirable to provide for continuous testing by non-destructive means. It was therefore considered necessary to devise improved equipment and a suitable method for this purpose, as described in this report.

To begin with, however, consideration should be given to the relative merits of continuous test methods and of standard test methods as regards accuracy, reliability, and operating economy. In standard methods, the grading of electrical sheet is based on measured values obtained from specially prepared samples of the material supplied, and provides a very considerable degree of accuracy by subjecting specimens of suitable size and shape to magnetic measurements under well-defined conditions. Such methods have, however, the disadvantage that the properties are investigated on arbitrarily selected specimens, which cannot be used again afterwards in the construction of motors or transformers, so that the properties of the sheet actually used in the construction are inferred indirectly from the random-sample tests, the extent to which they are representative depending on the degree of uniformity of the material. The results therefore give probable values, within certain limits, but lack absolute certainty, and this inherent disadvantage can only be avoided by testing every section of the material individually, logically leading to the use of some non-destructive method. Although frequently the accuracy of the continuous method cannot be as high as that of the standard method with measurements on randomly-selected samples specially prepared for testing, it would be of little use to base a comparison solely on relative accuracies without looking into other important aspects.

Determination of the properties of materials is subject to a degree of uncertainty which depends (a) on the accuracy of measurement and (b) on its validity, within certain limits of scatter, for a quantity of material regarded as belonging to the same grade or class. The uncertainty with regard to validity cannot be reduced by increasing measuring accuracy, since it is peculiar to each piece of material on which measurements are made and can only be eliminated by complete supervision of the manufacturing conditions of the material.

In continuous non-destructive testing, the only uncertainty is that resulting from measuring errors. Consequently, even if less accuracy is obtained than with the sampling method, the question as to which type of test will produce the more reliable indications will depend entirely on the homogeneity of the material considered.

As regards supervision of production, another point of view, frequently even more important than measurement accuracy, is the time needed to obtain test results, particularly when it is required to control the magnetic properties of passes of annealed strip in the heat treatment of electrical sheet. In this application, continuous measurements enable the furnace temperature and the annealing atmosphere to be adjusted to optimum conditions at any instant, so that, for practically every section of the strip, which may be up to 1500 metres long, the required quality can be reliably maintained. Supervision of this kind avoids possible complaints from users and increases efficiency, as well as the output, of the annealing plant by eliminating the necessity for subsequent treatment of batches which may not have the required loss-factor. The usefulness of a continuous non-destructive determination of the loss-factor, however, depends to a considerable extent on the position at which the measurements are taken in the production process. Continuous measurements give complete information on the magnetic values of a strip, but, if the guaranteed limits are exceeded at some points, it is necessary either to send back the entire strip for further treatment or to mark and perhaps cut off the corresponding areas; even if this were permissible, it would cause complications, delays, and additional expense. For strip-testing equipment, therefore, the best position is between the exit of a pass furnace and the reeling equipment. At this position, indications of magnetic values are given at the earliest possible instant, and there is no requirement for a special rewinding unit which may

become an expensive item when heavy batches of strip are to be handled.

Test Equipment

The test equipment used, which has produced good results and which has been operating for a number of months, is shown diagrammatically in Fig. 1, in which the strip (1) from the annealing furnace passes through the thickness-measuring gauge (2), situated immediately before or after the test coil, and thence over the pole surfaces of the laminated yoke (3). The portion of strip, of thickness d, between the poles is surrounded by the magnetizing coil (4), which also carries the induction measuring coil (5). The rollers (6) determine the level of the strip, which is under a moderate tension. The 50-cps magnetizing current is obtained from a variable-voltage transformer (7) and is passed through a precision-type current transformer (8), which converts it to values within the measuring range of the current-carrying coils (9) of the wattmeter, of which the voltage coil (10) is fed by the induction measuring coil (5). The same voltage, supplied to the voltmeter (11) via a synchronous switch (12) is used to indicate the peak value of flux in the strip. Because of the relatively large air gap in the induction coil (5), the voltage produced by the flux through the gap is compensated by means of a variable a.c. inductance (13) in such a way that, even with a multiple of the normal excitation current, no deflection occurs at the voltmeter (11) if there is no strip within the coil.

The wattmeter deflection is produced by the electrical power in the magnetized piece of strip, converted into heat in the yoke, the voltage coil of the wattmeter, and the averaging voltmeter (11). The wattmeter voltage circuit (10) has a resistance of 1000 ohms, in which, with a voltage of 5 V only rarely exceeded, 0·025 W are lost. The yoke has a cross-section which is between 50 and 100 times greater than that of the magnetic strip, the induction

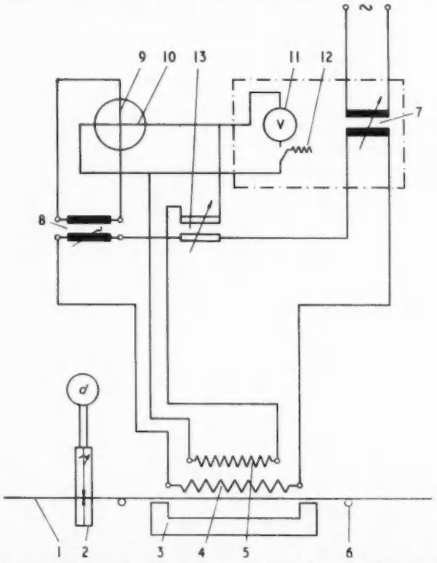

Fig. 1. **Diagrammatic arrangement of the continuous testing equipment.**

in the yoke being between 100 and 200 gauss, and corresponding to a magnetization loss of 0·1 to 0·2 mW/kg. These additional losses should be compared with the losses in the strip itself, which are of primary interest, and which, for an effective weight of 3 kg for the iron, amount to approximately 5 W if the loss-factor at 10 kiloguass (the L_{10}-value) is, for example, 1·7 W/kg. The effect of the yoke is therefore to increase the L_{10}-value of the strip by 0·07 to 0·13 W/kg, i.e., by about 4% to 8% of the measured value in the example considered.

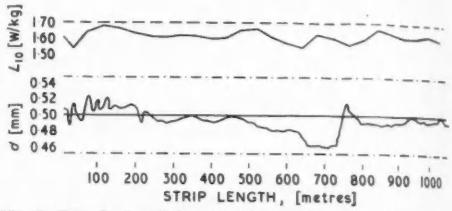

Fig. 2. **Record of variations in thickness d and L_{10} -values along the length of a strip of electrical sheet.**

Actually, it would be possible to take account of all the additional losses by means of a table or a chart, and the final result could then be given for the iron loss itself. In practice, however, this would confer hardly any advantage, since, with the strip-testing equipment used, the magnetizing effect is only in the rolling direction, which, in the case of non-grain-oriented sheet, gives rise to losses which are from 5% to 10% lower than those of the Epstein specimen, which is measured half lengthwise and half transversely. Thus, if no additional refinements are introduced in order to compensate the losses in the yoke, these losses will approximately cancel the apparent reduction in the value of the loss-factor caused by the purely longitudinal magnetization. Moreover, the main purpose of strip testing is to ensure uniform quality control and, for this purpose, none of the refinements of "absolute" measurement needs to be taken into account, particularly because at least two Epstein specimens will normally be taken from each strip and tested. After a few days, the extent of the scatter in the measurements can be assessed and it is then possible to determine the permissible limits of the strip-testing equipment, so as to be certain of fulfilling acceptance requirements.

The measurements are evaluated from the weight and the power loss of the portion of strip under test (using the wattmeter reading), for the peak value of magnetic induction on which the results are to be based. Thus, the L_{10} or L_{15}-value is obtained, and the measurement, evaluation (with the aid of nomograms, etc.), and recording of each result take only a few seconds. The corresponding instantaneous strip thickness is automatically measured and continuously recorded on a paper strip by suitable thickness-measuring equipment located close to the wattmeter.

Practical Test Results

As an example, typical results obtained in a quality-control test on magnetic strip with this continuous method are shown in Fig. 2, in which variations in strip thickness d and L_{10}-values are plotted along the 1000-metre length of a strip of electrical steel. It should be noted that the L_{10}-

values determined from Epstein testpieces at the beginning and end of the strip show good agreement with those obtained by the continuous testing method, being 1·58 and 1·63 W/kg respectively.

Experience with this continuous magnetic testing procedure indicates that it results in increased operating reliability and economy in the annealing process, and also enables direct information to be obtained regarding the various important relationships between annealing conditions (i.e., strip speed, annealing temperature, and composition of protective gas) and the magnetic values of the strip.

ITALY

Fatigue and Other Tests With Progressively Increasing Loads

By L. Locati. (From *La Metallurgia Italiana*, Vol. 51, No. 5, May 1959, pp. 179–184, 5 illustrations)

In materials testing, there are many investigations where the development of a phenomenon must be followed as a function of time, such as ageing and plastic flow, or as a function of a periodic repetition of events, such as fatigue.

Usually, the development of these phenomena is studied by means of tests in which the influencing parameter or parameters are kept constant, while the quantity under consideration is determined as a function of time or of the number of cycles. The tests are then repeated for different values of the parameters, in order to obtain a sufficiently complete picture of the phenomenon.

Sometimes, it is possible to "synthesise" the results by means of a mathematical expression related to the physical law which governs the phenomenon, as in the case of ageing, for example; in most cases, however, only an empirical formula is obtainable, representing with a varying degree of accuracy the experimental curves. In such cases, extensive test programmes appear inevitable and, if the tests are of long duration, the results will become available only after very long delays, so that it becomes particularly important to have a suitable method for accelerated testing.

This situation has been particularly apparent in fatigue tests, and attempts have been made to replace tests at constant load by a test with gradually increasing load. Thus, Prot was the first to propose such a method as a means of assessing materials, and his suggestion has raised considerable interest, because it enables an appreciable saving in time and costs to be made.

This method, using a progressively increasing load, can now be made of more general use in many other applications and, in the following, examples of its possibilities will be given. Basically, the method comprises increasing the applied load progressively during the course of the test itself in such a way as to increase the rate of development of the phenomenon, thereby shortening the testing time. The progressive increase in load can be effected either in steps or continuously, as shown in Fig. 1, which compares tests of load as a function of test duration under constant load (*A*, *A'*, and *A"*) with loads increasing progressively in steps (*B'*) or continuously (*B*). A test with continuously increasing loads can be regarded as a sequence of constant-load tests of short duration, with a total effect which is the sum of the corresponding partial effects.

This method of progressively increasing loads can be applied with advantage if its results can be correlated with those obtained from constant-load tests. For this purpose, it is necessary to know (from preliminary data) the general relationship between the phenomenon concerned and the variable parameter, and also to be able to assume that (1) the phenomenon develops at a constant rate when the parameters affecting it are kept constant, and that this rate is not affected by previous partial development; and (2) the total effect can be regarded as the sum of the partial effects, irrespective of the sequence in which these are produced. It is true that presumably no phenomenon exactly fulfils these assumptions but, in practice, they can be regarded as valid if the degree of approximation is stisfactory.

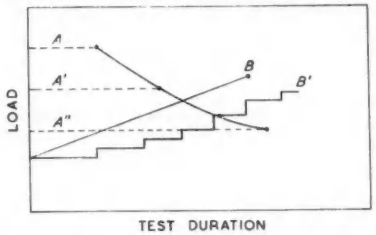

Fig. 1. Comparisons of test duration under constant load (*A*, *A'*, and *A"*) and with loads increasing progressively in steps (*B'*) and continuously (*B*).

The evaluation of the results of a test with a progressively increasing load is usually easy and fairly rapid, and the equivalent value for a constant-load test can be readily derived by calculation or by means of a graphical construction. In some cases, the calculation reduces to a simple multiplication by a predetermined coefficient, based on previous experience.

Fatigue Tests

In conventional fatigue tests, the specimens are subjected to a load of a magnitude which is constant, or regarded as constant, throughout the test. Closer examination indicates, however, that there is a constant magnitude of load only for as long as the initial crack is not produced; when a crack occurs, even if the magnitude of load is kept constant, the stress level will vary considerably and in a different manner from one case to the other. Thus, the assumption of testing at a constant stress level is not strictly accurate.

In tests with progressively increased load, the load is increased during the test itself until rupture occurs, and the rate of increase can be either constant or variable.[1] With different rates of increase, the fatigue limit can be obtained graphically, by means of a straight line joining the representative points at which fracture occurs, in a diagram of load plotted against the square root of the rate at which load is increased.

Prediction of the fatigue curve will also be useful for specimens of materials of the same grade or for similar components. The procedure, which has been explained

in detail elsewhere,[2] consists of choosing a hypothetical fatigue curve, and displacing it on the *S-N* diagram until the "cumulative damage," calculated as explained later, is equal to unity.

In conventional fatigue tests, all specimens are not fractured, the unfractured specimens being only partially significant, whereas with the progressive method all specimens are ruptured and provide usable information. Test results, and the determination of the amount of scatter, are obtained much more rapidly than by the usual method.

An approximate determination of the fatigue limit can be obtained even if only one specimen is available for tests ; this possibility is of value in investigations of new materials or for special or expensive specimens used, for instance, in aircraft structures. Obviously, since the fatigue limit has only a statistical significance, it may seem illusory to try to determine it from a single specimen. What is obtained is, in fact, the fatigue strength of the particular specimen, which provides a quantitative result, without risking a choice between a test load which may be too low for rupture, and a load which may be so high that it results in an unduly rapid, and therefore not significant, rupture of the specimen.

The method of progressive loading applied in fatigue tests has been employed by a number of other investigators[3, 4, 5, 6] with very encouraging results.

Creep Tests

When specimens are subjected to continuous loading at a high temperature up to a predetermined value of permanent elongation, or, more usually, until rupture occurs, the phenomena under consideration (plastic flow and gradual crack formation) are also functions of time. The rate of development of the phenomena is affected by temperature and load, so that test specifications provide for strictly constant conditions for these two parameters. Also, these tests are frequently of considerable duration, in some cases much longer than expected. This occurs, for instance, in acceptance tests, where non-uniformity of the specimens may give rise to scatter extending over a range from, say, 1 to 10, or in initial tests on a material when nothing is known about its behaviour.

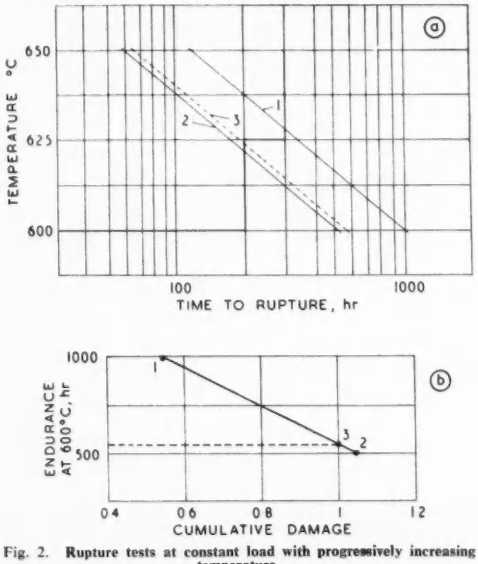

Fig. 2. **Rupture tests at constant load with progressively increasing temperature.**

Far more rapid results are obtainable by progressively varying one of the two influencing parameters, i.e., either temperature or load, the other parameter being kept constant. To apply the method, it is necessary to know the law according to which the parameters affect the phenomenon. Thus, if load is to be increased, it is necessary to have a curve of endurance as a function of load only. If it is decided to vary the temperature, the influence of temperature on endurance must be determined. In practice, however, it is sufficient if the influence of the parameters is known in the neighbourhood of the points being explored ; this information is generally derived from tests on other fairly similar materials or from formulæ which represent the physical law of the phenomenon.

Endurance is generally related to load by an equation of the type $1/t = AS^m$, where t is the time, A is a constant, S is the stress level, and m is an experimental exponent equal to or greater than unity. As a function of temperature T, endurance can be derived from the equation $1/t = Be^{-C/T}$, where B is another constant and C is the " intensity coefficient " of the phenomenon. Thus, to apply these relations, approximate values of m or C are required ; moreover, it is always assumed that the law of cumulative damage is valid.

An example of the way in which cumulative damage is estimated is shown in Fig. 2, which refers to rupture tests at constant load with progressively increasing temperature carried out on specimens of an alloy steel containing 0·25% C, 24% Cr, 20% Ni, and 2% Mn, subjected at a stress level of 20 kg/mm² to a temperature of 600° C for 200 hr, 625° C for 100 hr, and 650° C for 6 hr, rupture occurring after the 6 hr at 650° C. Now, if the hypothetical curve (1) in Fig. 2a represents endurance with 1000 hr as the rupture limit at 600° C, 330 hr at 625° C, and 115 hr at 650° C, the cumulative damage is $(200/1000)+(100/330)+(6/115) = 0{\cdot}2+0{\cdot}3+0{\cdot}05$ approximately, or about 0·55, i.e., considerably less than unity. If, however, another hypothetical curve (2) is drawn parallel to curve (1), representing a rupture limit of 500 hr at 600° C, 180 hr at 625° C, and 60 hr at 650° C, the cumulative damage is then $(200/500)+(100/180)+(6/60) = 0{\cdot}4+0{\cdot}55+0{\cdot}1 = 1{\cdot}05$, i.e., much closer to the value of unity denoting rupture, as represented by curve (3).

From these calculated values, it is possible to plot, as shown in Fig. 2b, a diagram of endurance at 600° C as a function of cumulative damage, using (1) a cumulative-damage value of 0·55 for 1000 hr, and (2) a value of 1·05 for 500 hr. Thus, the estimated endurance at 600° C, corresponding to point (3) for a cumulative-damage value of unity, is about 540 hr. As a result, bearing in mind that the actual test entailed a total of $200+100+6 = 306$ hr, a total of $540-306 = 234$ hr of testing time has been saved.

The objection might be raised that, as the slope of the hypothetical endurance curve is assumed, the entire test could have been carried out at a higher temperature, e.g., at 650° C. It is true that this could have been effected satisfactorily in this particular example, but it should be borne in mind that it is preferable for the specimen under investigation to be tested under conditions which are not markedly different from those

it will have to sustain in practice, as unduly accelerated tests are liable to give misleading results.

Wear Tests

The method of progressively increasing load can also be applied in wear tests and in the study of conditions leading to seizure. The experimental equipment can be, for instance, an eccentric disc rotating on a specimen mounted on a leaf-spring. Contact occurs along one of the generating lines of the specimen, and the position of contact is continuously altered, the resulting friction possibly leading to seizure. As wear is a function of time, with the applied load as the governing parameter, it can be investigated in tests with progressively increasing loads in the same way as for fatigue tests. Below a certain load, failure is avoided by suitable changes which occur in the surfaces of the two materials in contact. Beyond this load, which is the " seizure limit," extensive damage occurs.

As in fatigue tests, the progressive method can be employed to determine the seizure limit from the results obtained with a single specimen. In a Wöhler diagram, a set of hypothetical *S-N* curves (consisting of an initial steeply decreasing portion, followed by a horizontal portion) are drawn. The stepped lines of results of the progressive test are plotted in this diagram, and the results are evaluated so as to obtain the cumulative damage. However, because in this case tests by the conventional method also show a somewhat greater endurance than that derived from the progressive test, it is advisable to determine the cumulative damage for a value of 1·2 instead of unity.

For instance, assume the hypothetical curves are for loads of 120, 140, and 160 kg. If the endurance limits for a curve with a seizure limit at 140 kg are assumed to be $1{\cdot}6\times10^6$ cycles at 166 kg, 10^6 cycles at 177 kg, $0{\cdot}7\times10^6$ cycles at 188 kg, etc., and the specimen is subjected to 45,000 cycles at each of these loads, the cumulative damage can be calculated as outlined previously, similar calculations being made for the other hypothetical curves. Cumulative damage is then plotted as a function of load (for maximum permissible wear) against relative damage, and the critical value for the pair of metals considered is thus determined.

Tool-Life Tests

In the case of tool-life tests, the considerations are the same as in wear tests. Curves exist which indicate the life of a tool tip at various cutting rates for otherwise constant conditions as regards feed, depth of cut, etc. The results obtained with the progressive method of testing, using gradually increasing cutting rates, show that it is suitable for tool-life tests.

Indicative Trends

The method can also be used to obtain additional information on changes in the properties of a material during tests. If the resistance of the material is improved by protracted " running-in " conditions, then the cumulative damage indicated by the results of the progressive test will be higher than that from a conventional test. This is particularly so in the case of wear tests. Thus, a comparison of results of ordinary tests with those of accelerated tests will give indications on running-in phenomena.

Rate of Increase in Load and Initial Value

The question as to what rates of increase are to be used in these progressive tests with increased loading is not easily answered. The progressive test is defined by two load values, i.e., the initial value and the rate at which it is increased. Investigations have shown[3] that the results of fatigue tests with progressively increasing loads are hardly affected by the initial load level, although it should be given careful consideration in order to make the best use of the test method.

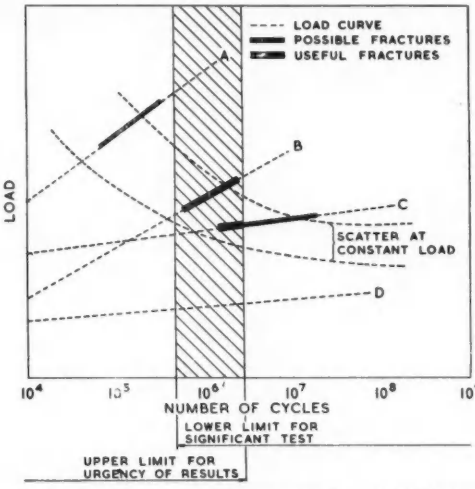

Fig. 3. **Probability of useful fracture, depending on initial load and rate of increase of loading.**

The rate of increase of the load will depend on the extent to which the phenomenon under study is sensitive to variations in load (or any other variable parameter). Fig. 3 shows that, as regards its duration, the range to be explored should be chosen between an upper limit, which depends on the urgency with which results are required, and a lower limit, below which the test is unduly accelerated and tends to lose some of its significance. The " programme " chosen should be such that it will have the maximum probability of giving useful results in the range of endurance values desired.

Fig. 3 also shows the range of scatter obtained from constant-load tests. Considering the desired range (shown shaded in the diagram) and the limiting curves of scatter, it is seen that, in this example, programme *A* has no prospects of success, programme *C* has a slight probability of success, and programme *D* is far too slow, programme *B* being the most suitable.

The choice of the rate of load variation can be made easier when it is possible to follow the development of the phenomenon with sufficient accuracy during the test. For instance, in a creep test, the creep rate is usually recorded. In this manner, the information collected during the test can be used to modify, if necessary, the rate at which the parameter is varied.

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U. S. A.

Concentricity Meter for Measuring the Air Gap in Electrical Machines

By O. DAHLE and O. UGLUM. (From *Control Engineering*, Vol. 6, No. 7, July 1959, pp. 127-128, 4 illustrations)

WHEN adjusting the position of the rotor in the air gap of medium-sized electrical machines, the conventional procedure is to measure the air gap between the rotor and stator at several points around the periphery by means of wedge-gauges. This is, however, essentially a trial-and-error procedure, with the obvious disadvantage that it may have to be repeated several times before the specified tolerances are obtained. Furthermore, conventional wedge-gauges can give erroneous results, because of random local irregularities, and the procedure necessitates making the air gap accessible from both ends of the machine, possibly leading in some cases to uneconomical and impractical designs for cooling fans, bearings, etc.

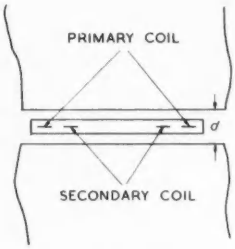


Fig. 1. Cross-section of the transducer in an air gap.

Now, however, a new continuous method, developed in Sweden at the ASEA Research Laboratory, makes it possible to measure the air gap at the remote end of the machine. The principle used is that the mutual inductance between two coaxial single-layer pancake coils, arranged as shown in Fig. 1, is dependent on the air gap *d*. The transducer coils, placed between two strips of impregnated paper and glued together, are located at one end of a probe, which is 800 mm in length, 23 mm in width, and 0·3 mm in thickness. The other end of the probe is fitted with a plug.

The schematic arrangement of the centring equipment is shown in Fig. 2, in which four of these transducers, used simultaneously, are offset by 45 deg. The primary windings of all these transducers are fed in series with a constant 60-cps current. Amplifiers A1 and A2 have phase-sensitive rectified outputs and inputs consisting of the difference between the output voltages of transducers (1) and (3) and of (2) and (4) respectively. The outputs of amplifiers A1 and A2 are connected to two conventional moving-coil meter movements, arranged in a single instrument I, with the pointer in 45-deg. directions at zero output from the amplifiers. The position of the centre of the rotor in the air gap corresponds to the intersection of the pointers with respect to the centre of the circles on meter I.

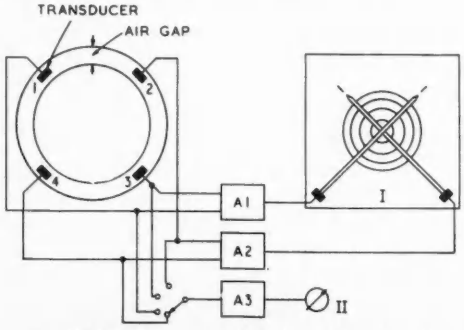


Fig. 2. Schematic arrangement of the centring equipment.

For centring, the transducers are adjusted one by one in the gap for maximum output on meter II from the amplifier A3. As a result, they cannot be located opposite a slot in either the rotor or the stator. The position of the rotor is then adjusted until the pointers of instrument I intersect at the centre. The rotor is locked in this position, and the transducers are placed at the other end of the rotor (with certain machines, it may be necessary to readjust the rotor position at the original end or to duplicate the equipment).

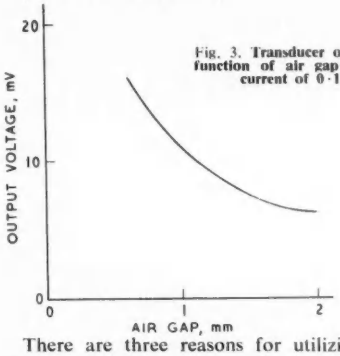


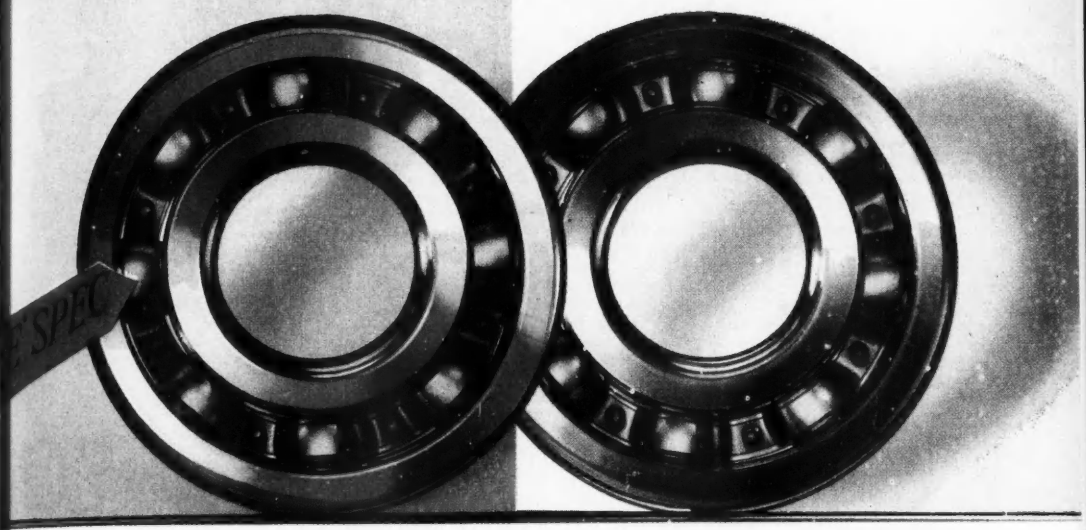
Fig. 3. Transducer output voltage as a function of air gap for an excitation current of 0·15 A, 50-cps.

There are three reasons for utilizing the mutual inductance between two coils, instead of the self-inductance of one coil. Firstly, the impedance of a single-layer coil in an air gap, as in Fig. 1, is mainly ohmic, so that variations in self-inductance due to different air gaps will be difficult to detect. Secondly, the lines of magnetic flux in the air immediately surrounding the current-carrying coil will contribute very little to the mutual inductance. Thirdly, with mutual inductance, the position of the transducer in the air gap is not critical.

The output voltage of the transducer as a function of air gap *d*, when excited by a 50-cps current of 0·15 A, is shown in Fig. 3, the curve being approximately hyperbolic and applying to laminations of 3% silicon iron. Measurements show that the output voltage is independent of the position in the gap.

This equipment has been used in production for some time and has been found to give satisfactory accuracy, i.e., less than $\pm 0{\cdot}05$ mm. The air gap transducers can also be used for measuring a single air gap, by using a single transducer and a calibration curve of the general shape shown in Fig. 3, or by balancing the output of two transducers, one being placed in a calibrated and adjustable air gap and the other in the air gap to be measured.

PENNY PLAIN



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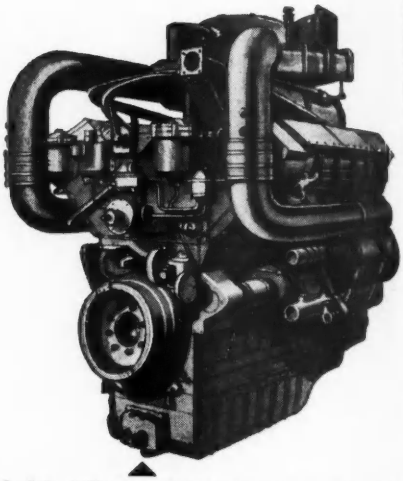
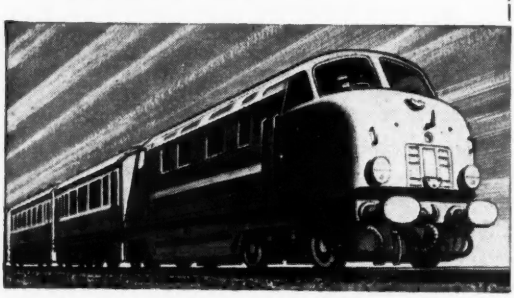
MAYBACH POWER MADE IN BRITAIN

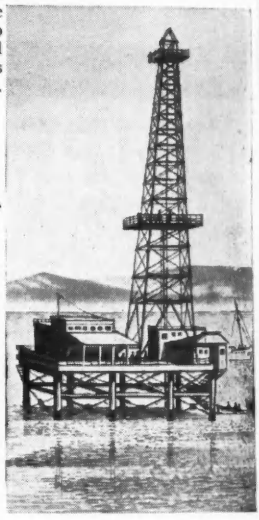


Typical of the MD range of engines is this Type 650 12-cylinder supercharged model with cylinders arranged in 'V' formation.

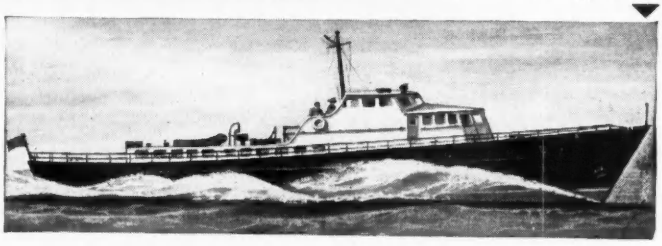


Railway Traction 220-2,000 B.H.P.

Industrial Plant 220-1,750 B.H.P.



Marine 220-3,000 B.H.P.



Bristol Siddeley have the exclusive manufacturing and selling licence in the United Kingdom for the world-famous Maybach MD range of In-line and 'V' form diesel engines. These diesels range from 4-cylinder engines of 220 hp to 16-cylinder engines of 3,000 hp. They have an outstanding record of performance and reliability over millions of miles on railways throughout the world, and are widely used for marine propulsion and industrial power generation of all kinds.

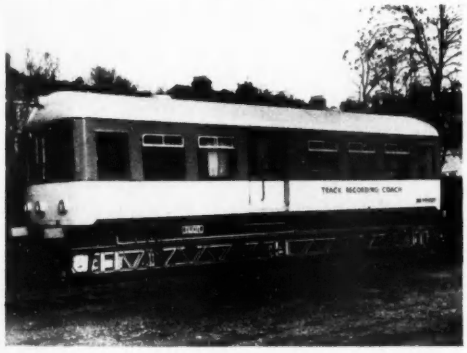
BRISTOL SIDDELEY Maybach DIESEL ENGINES

BRISTOL SIDDELEY ENGINES LIMITED, COVENTRY, ENGLAND

British Industrial Developments

Track-Recording Coach for Railways

A new track-recording coach, the only one of its kind ever built, has been developed for British Railways by Elliott Brothers (London) Ltd., and is designed to pinpoint and record even the smallest irregularities in railway tracks. By means of a system of electrical measurements, the coach verifies and records on a moving chart the track gauge, the regularity of track curvature, and, by relating axle movement to a high-speed gyroscope, whether curved tracks are banked at exactly the correct angle for express-train speeds. Capable of being driven at either end, the coach is a four-wheeled vehicle fitted with a 97-hp diesel engine, mounted horizontally under the floor, and can travel at speeds up to 55 mph, though it is limited to 30 mph when recording. A separate engine, coupled to a 5-kW generator, supplies electrical power for instrumentation, lighting, and heating. The coach is completely self-contained and includes cooking, washing, and toilet facilities for the crew.



The latest automation techniques for obtaining, transmitting, and recording measurements have been used. For the measurement of cant or super-elevation, a datum is provided by the high-speed gyroscope, enabling the coach to operate accurately at any speed up to the limit, regardless of curvature or gradient. Curvature and gauge are obtained by measuring the movements of a system of probes which contact the inside edge of the head of the rail, these probes being designed to negotiate track fittings at the maximum recording speed and carried on a lattice-girder framework supported at the axle-boxes. To ensure that the axles can follow the track without restraint, the points of support of this framework are arranged to give the necessary degrees of freedom, permitting the axles to twist relatively in both the vertical and lateral planes. In addition, springs limit the shock which the framework receives when the wheels are subjected to several vertical accelerations. The sensing probes are spring-loaded against the rails, and special guide-shoes, running in the opposite flange way, ensure their passage through gaps at points and other fittings and prevent the sensing-shoe from taking the wrong route at actual openings in crossings. This specially developed Elliott system obviates the need for the use of the long probes normally required to span gaps at points and crossings. In fact, the probes used in the new coach are of small size and are therefore extremely sensitive detecting elements of low inertia, giving an immediate and accurate response to any deviations from line or gauge.

In operation, the probes are held down by compressed air and can be withdrawn clear of the track when not in use. A special emergency switch is also provided, enabling the probes to be retracted by the observer if obstructions are seen on the track. The probes can be lowered again on any piece of straight or curved track without having to stop the coach, and their rubbing faces consist of a welded deposit which can be renewed when required.

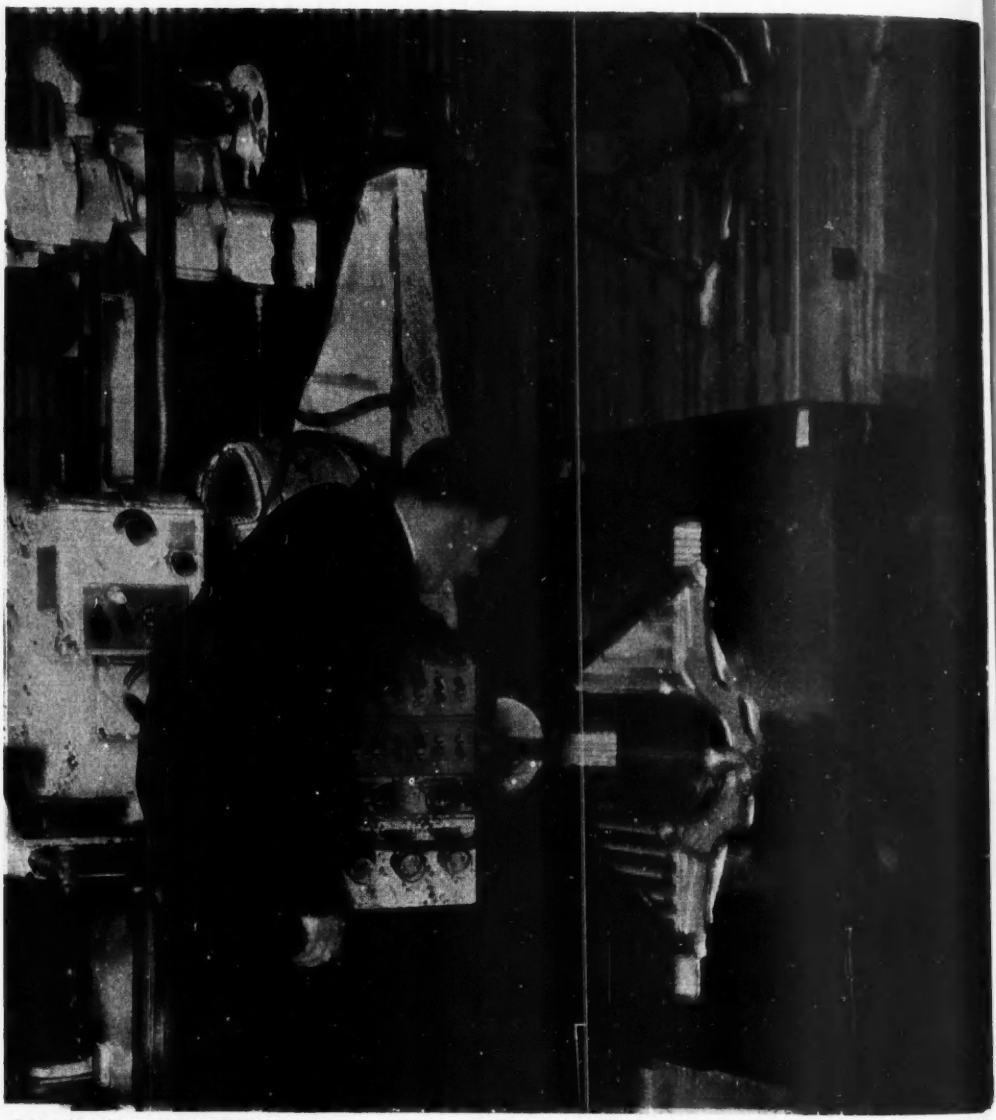
Measurements of curvature, gauge, and cant are obtained as a.c. signals which are linearly demodulated and the resulting d.c. signals applied to high-sensitivity mirror galvanometers. The records are produced by these galvanometers on a special photographic paper by reflected beams from an ultra-violet light source and are presented as traces on a multi-channel recorder. At the same time as these records are being made, a previous chart of the same piece of track can be viewed on an adjacent display, this comparison enabling any deterioration to be spotted immediately. Any maintenance work carried out since the last run can also be checked. In addition to the main measurements, the records include the speed of the coach, distance marking, facilities for indicating events such as stations, and space for making notes.

Metal-Diffusion Chromizing Process

Representing a considerable advance on earlier metal-diffusion techniques, the " Dicrom " chromizing process, announced by Metal Diffusions Limited, of Isleworth, Middlesex, is capable of producing a depth of diffusion of between 0·001 and 0·015 in., the function which the item treated is to perform determining the depth of diffusion that can economically be justified. The main advantage of the " Dicrom " process lies in the high purity of the chromium provided at the surface, i.e., above 60%, as compared with other chromizing processes, which rarely produce a surface purity of over 50%. In fact, surface-purity values of up to 96% can be obtained with the " Dicrom " process, though for most commercial applications, a depth of diffusion of from 0·003 to 0·005 in., with a surface concentration of chromium between 60 and 75%, gives very satisfactory results.

The superior surface properties obtainable with the process ensure that, in cases where special resistance to oxidation is required at temperatures up to 1180°C, mild steel can be treated to afford the same resistance to corrosion as that of a 40%/22% Ni/Cr steel, but usually at between one-third and one-half the cost. By employing combined chromium/aluminium diffusion, effective resistance to corrosion at temperatures up to 1305°C can be obtained. When sulphur-bearing gases are present, adequate resistance to corrosion can be obtained by chromizing, followed by superficial high-temperature oxidation of the surface to chromic oxide. However, in cases where dew-point conditions are also liable to occur (as in boiler flues, where acid corrosion of economizers, grit arresters, fly-ash precipitators, and such plant is a serious problem), a superior degree of protection is achieved by alloying another metal with the chromium.

Where cyclic temperature conditions are encountered, in combination with the presence of sulphur gases and water vapour, nickel/chromium alloy steels are subject to sub-surface reactions, owing to the presence of nickel, whereas chromium, either alone or alloyed with molybdenum, vanadium, or aluminium, affords greatly improved performance characteristics under these rigorous



FORGED STEEL DIE BLOCKS

Milling operation being carried out on a Keller copy milling machine at the Forging Division of HIGH DUTY ALLOYS LTD.

by

FIRTH BROWN

ALLOY STEELMAKERS · FORGEMASTERS · STEEL FOUNDERS · HEAVY ENGINEERS

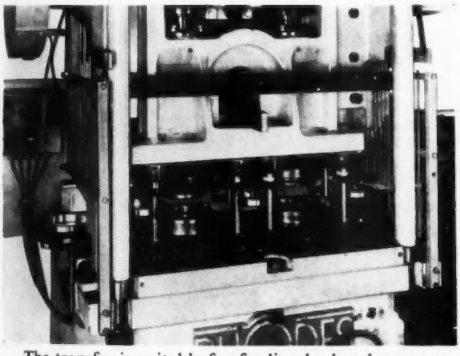
THOS FIRTH & JOHN BROWN LIMITED SHEFFIELD · ENGLAND

conditions. For such purposes, therefore, a relatively inexpensive steel which has been " Dicrom "-treated to provide a high value of chromium concentration at the surface can prove to be superior to nickel/chromium alloy steels.

Another advantage of the higher percentage of surface chromium provided by the process permits fuller use to be made in a wide range of applications of the physical properties of chromium itself, including extreme hardness, low coefficient of friction, resistance to abrasion, and virtual immunity to oxidation or attack by many chemicals, including sulphuric and nitric acids, with the ability to maintain these properties over a wide temperature range. Furthermore, the chromized surface can be electro-polished to produce a finish which is comparable with that of chromium plating, while still retaining the advantages of heat resistance and of inseparability from the parent metal. Also, the overall cost is competitive.

Transfer Feeds for Power Presses

Transfer feeds for existing presses, and in many cases for existing tools, are now available from Press Equipment Ltd., of Birmingham 19. In its simplest form the transfer comprises two pick-up heads, simultaneously gripping a blank component from a location outside the tool area and the processed component from the press tool, lifting to clear locations and die form, traversing, and then lowering the blank into the die and the processed component onto an ejection chute. For more than one tool, an additional pick-up head is required for each station, so that the component is progressed through each tool until it reaches the ejection point. Pick-up is achieved by either vacuum suction cups or air-operated grip-fingers, adjustably mounted on a carriage which has a compounded motion of vertical lift and horizontal traverse.

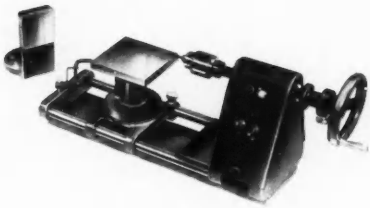


The transfer is suitable for feeding by hand or magazine location; alternatively, blanks may be taken from coil material that is decoiled, straightened, and fed direct to a blanking tool by the bow-feed method developed by the Company, this combination providing a completely automatic line.

On presses with speeds of up to 24 strokes per minute and with suitable stroke and tool daylight, the transfer is usually driven from the crankshaft, and the press runs with the clutch continuously engaged. On faster presses, and where tool daylight is restricted, the transfer is self-motorized and engages the press clutch at each cycle after the components have been transferred and located, and the carriage has returned to its mid-position. Removal of the processed component is automatically checked at every stroke to ensure tool protection. The illustration shows a two-tool, three-head transfer, set up to produce 720 components per hour with one operator, in place of the two presses and two operators previously required to produce about 400 components per hour.

Hand-Operated Tapping and Reaming Machine

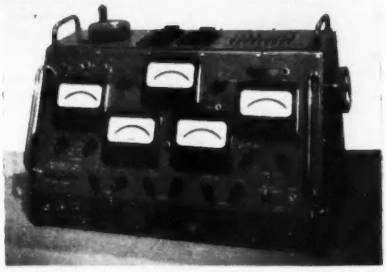
Distributed in the U.K. by Monks & Crane Ltd., of Birmingham 33, the " Andytap " is a versatile, sensitive, hand-operated, bench-type machine designed for the accurate tapping and reaming of small components such as pressings, stampings, brass and aluminium castings, and mouldings. The machine is solidly constructed, is simple to use, and is easily and quickly set for right-hand or left-hand threads.



Supplied complete with an angle plate, tool-post, adjustable table, ¼-in. chuck, and operating keys, the new machine incorporates a two-light signal system (" caution " and " stop ") for tapping blind holes or for use where a tap has to go to a required depth. These signal lights are battery-operated and can be used independently alternatively, a loose collar can be locked for rotary work, without using the lights.

Thermionic-Valve Analyser and Bridge

An improved version of a thermionic-valve analyser, embodying a special bridge manufactured in France by the Compagnie Générale de Metrologie, of Annecy, and distributed in the U.K. by Metrix Instruments Limited, of Surbiton, Surrey, makes it possible to measure both the static and dynamic characteristics of valves rapidly and accurately under any operating conditions. Thus, as distinct from many valve testers of the simple " good-doubtful-replace " type, the new analyser, designated the " Metrix " type U-61B, is an accurate, comprehensive instrument which provides a detailed analysis of the static characteristics of all receiving-type valves and low-power transmitting-type valves. In addition, thyratron control characteristics and neon-tube regulation curves can be plotted, as well as positive grid characteristics. Facilities are also included for checks on filament continuity and insulation, short circuits, and gas leaks.



Five large mirror-scale meters serve to indicate simultaneously and accurately heater, anode, and screen voltages, and anode or screen currents, while four separate, adjustable, stabilized voltage sources provide the necessary electrode voltages, all of which are readily

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accessible for external use by means of sockets on the front panel. Any desired elements can be inserted in series or in parallel with any of the electrode circuits, and adjustable anode loads and parasitic stoppers are incorporated. A comprehensive protection system provides overload cut-outs in both the d.c. supply and mains circuits.

The valve bridge, designated type 661, which can be used independently or in conjunction with the U-61B analyser, is intended for the measurement of the dynamic, as opposed to the static, characteristics of the valve under test, enabling a wide range of amplification-factor, internal-resistance, and slope measurements to be made rapidly.

Vibratory Metal-Finishing Machines

The Roto-Finish Company, of Kalamazoo, U.S.A., are now marketing a range of metal-finishing machines in which a new principle is employed, involving the use of a vibratory motion, instead of the rotary motion of conventional types of metal-finishing barrel. The range produced in the U.S.A. comprises four models, with capacities from 1 to 7 cu ft (the 7-cu ft model is illustrated in Fig. 1), but, in Great Britain, Roto-Finish Ltd., of Hemel Hempstead, Herts., are working on the development of a range of similar machines with features and capacities suitable for European industries, and are also developing a two-tank vibratory machine which it is believed will have additional advantages over the single-tank type. The company expects to be able to announce details of a range of these machines, specifications, and all necessary processing data in the very near future.

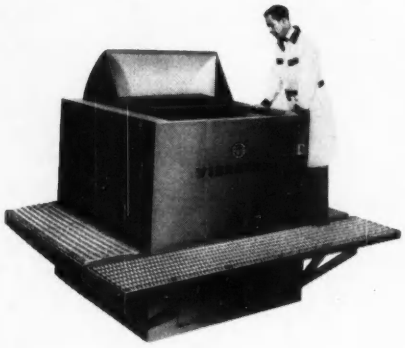

Fig. 1.

The vibratory system is stated to be from four to six times faster than conventional barrels, so that one of the new machines can do the same work in a given time as four to six barrel-type units of the same capacity, with consequent savings in time, labour, materials, and floor space, and at the same time providing faster and better descaling, deburring, radiusing, smoothing, etc. The reason for this increased efficiency is that, in conventional barrelling, the abrasive action takes place in a sliding zone which is a few inches in depth and which extends across the width of the rotating cylinder, as shown in Fig. 2 (left). Beneath this zone, however, little or no relative motion takes place between the components and the processing media, the mass being carried around in a position of repose until the point is reached where it commences to slide, so that very little work is accomplished in zone *A*. On the other hand, with the new vibratory system, the container holding the mass is subjected to a three-way vibration which produces an overall rotary motion of the entire mass, as shown in Fig. 2 (right), with a simultaneous movement of the individual

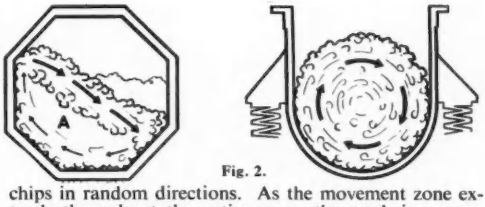

Fig. 2.

chips in random directions. As the movement zone extends throughout the entire mass, the work is accomplished much more rapidly.

Another advantage conferred by the vibratory motion is that internal surfaces can be treated as rapidly and as effectively as external surfaces, because, owing to the three-way movement of the chips, the media can flow through cavities at the same rate as over external surfaces. This is not the case with conventional rotary systems, where the amount of work that can be done on internal surfaces is severely limited. It should also be noted that larger work loads relative to capacity can be accommodated in the vibratory-type machine, principally because, as there is less impingement, fewer chips are necessary for cushioning purposes. Furthermore, these machines have an open-head container, so that visual control of the process is possible. Thus, a single component can be removed for immediate visual inspection while the plant is in operation and then dropped back. Also, the system is intrinsically more adaptable than conventional systems, and " continuous-flow " processing, in which parts emerge at the same speed as they enter, can be arranged without difficulty.

Pumps for Mine-Water Accumulations and Industrial Waste

Basically intended for coping with the difficult job of removing relatively small quantities of water accumulating at or near coal faces, though also suitable for handling industrial waste, a new range of pumps announced by Joseph Evans & Sons (Wolverhampton) Limited is capable of dealing with water containing impurities, solids, and gritty matter in suspension and can also work on snore. Furthermore, these pumps can stand up to rough usage and can operate for long periods with a minimum of attention, while the necessity for frequent and expensive replacement of working parts has as far as possible been eliminated. Also, bearing in mind the restrictions imposed by having to operate in confined spaces, their height and width have been limited to small dimensions. Two basic sizes are at present available, and each can be fitted with interchangeable liners of three different bores. The pumps are of relatively short stroke, so as to dipense with the need for internal gearing in the crankcase and to retain a low piston speed. The capacity range is 20 to 80 gpm, and the maximum head is 460 ft.

The pump is a totally enclosed duplex-piston type. The crankcase and skid-type base are of integral fabricated steel construction, combining extreme rigidity with low weight. The lubrication system to the crankcase is by splash and is entirely efficient with either direction of rotation and with the pump at a slight inclination from the horizontal. The crankshaft runs in roller bearings, and the crossheads have easily renewable guides, while the crankcase is fitted with a suitable inspection cover and is completely sealed against the ingress of dirt and dust. The liquid end is of the side-pot type, with individual valve boxes having separate covers. Valves can either be of the ball or rubber-sealed disc type. The pump piston has special Fluon sealing rings to reduce the heat generated when working on snore to a minimum. A simple chain-transmission drive between the motor and pump crankcase, enclosed in a heavy-gauge oil-bath case, is used, the motor being mounted on the pump base at the back of the crankcase.

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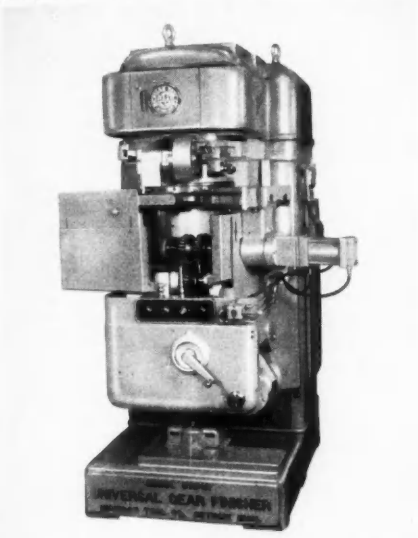
UX13

New Materials, Processes, and Equipment

UNIVERSAL ROTARY GEAR-FINISHING MACHINE

A new type of universal rotary gear-finishing machine, permitting gear shaving to be accomplished by various methods, has been developed by the Michigan Tool Company, of Detroit, Michigan. To accommodate gears with faces of varying widths and to perform crowning operations simultaneously with finishing, the machine is designed to cope with different set-up and feed methods, i.e., by the underpass method, the modified underpass method, and the transverse method.



In the underpass method, which is ideally suited to the rapid finishing of gears of nominal face width, of shoulder gears, and of gears to be crown-shaved, the cutter is slightly wider than the gear. The feed slide of the machine is set at right-angles to the axis of the work, and the work reciprocates once, over the cutter and return, with the cutter rotation reversing on the return pass. Reverse-crown cutters result in the desired crowning and finishing in one operation.

For modified underpass shaving, which is a most economical method of shaving gears and splines with a face width slightly wider than the cutter, the feed slide is set to feed the gear across the cutter at an angle to the work axis, the angle used being dictated by the amount that the gear is wider than the cutter. As in the case of underpass shaving, shaving contact is distributed across the full face width of the cutter.

Transverse gear shaving is a method which is applicable to the finishing of gears with a face width exceeding the capacity of underpass and modified underpass shaving. In transverse shaving, the feed slide is set parallel to the work axis, and the gear feeds across the cutter and back. At the same time, the cut is automatically fed upwards in controlled increments to the correct cutter distance for finishing the gear, a counter controlling the predetermined number of shaving cycles.

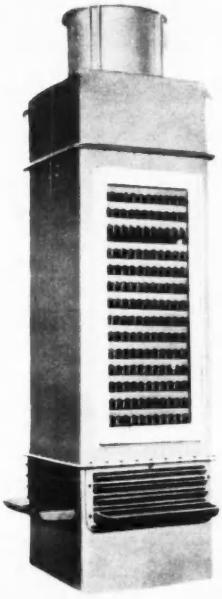
Central or off-centre crown shaving, tapers, or any combination of crown and taper can be effected by the underpass or modified underpass methods, using reverse-crown cutters ground to give the act crown desired. No extra time or cost is involved in this operation, no modifications are necessary to finish the gears, and no secondary set-up is required. This method is also the most suitable for crowning close-shoulder gears.

For crowning gears by the transverse shaving method the " rocker-motion " method is the most suitable, and for this purpose an adjustable cam and follower are provided for guiding the pivoted work-slide in a controlled rocking motion as the gear feeds across the cutter. Location of the high point of the crown can be varied by positioning the gear with respect to the pivot point.

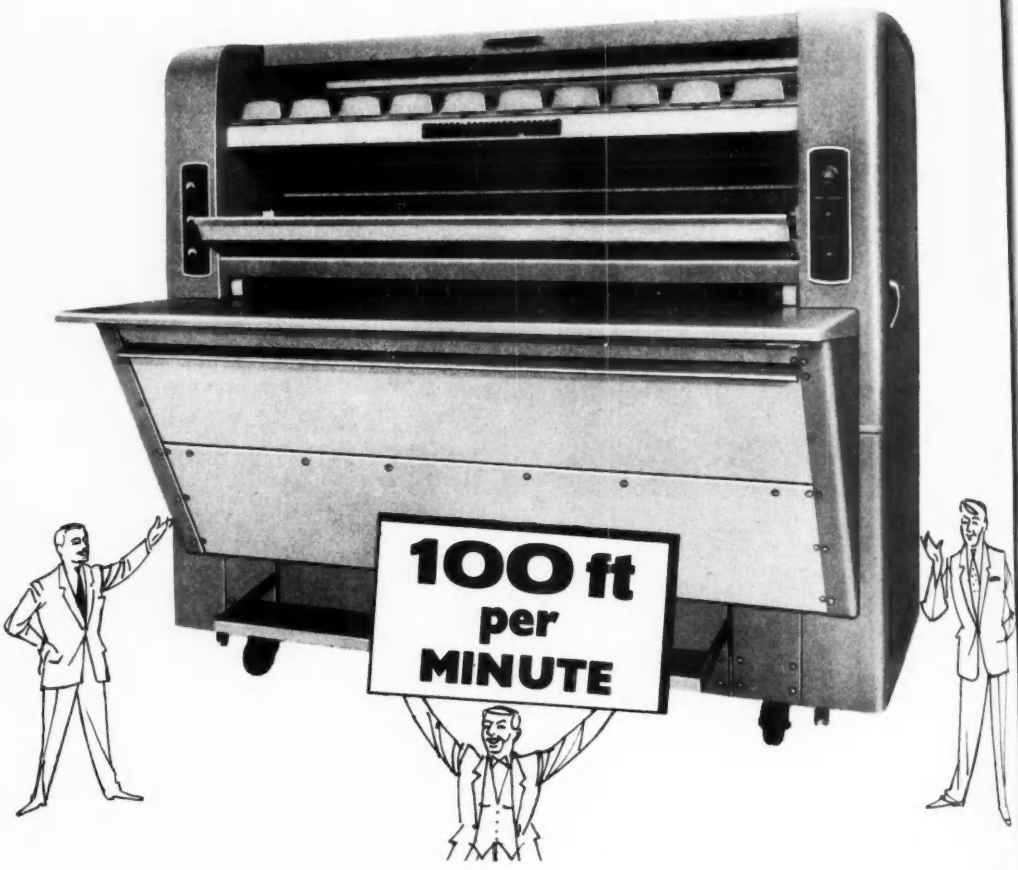
With the new machine, all work is carried out at above-the-waist level and is clearly visible. Furthermore, it is believed to be the only vertical shaving machine which is adaptable to straight-through automation on gears, with or without integral shafts. The construction of the frame permits loading and unloading from front to rear and, by the addition of a gravity-feed chute with a transfer loading device and automatic ejection, one operator can run a number of these machines merely by keeping the chutes filled. The automation system provided as special equipment can also be tied in with other machines performing other automatic operations.

PACKAGE-TYPE WATER-COOLING TOWER

Specially developed to meet the needs of industries requiring small-scale water-cooling facilities at a moderate cost, a complete packaged cooling tower developed by Film Cooling Towers (1925) Ltd., of Brentford, Middlesex, is available in capacities from 300 to 5000 gallons per hour, but is compact enough to be transported in a light lorry. Furthermore, the use of resin-bonded glass fibre in the construction of the basin, shell, and splash tray not only contributes to the lightness of the unit, but



PRINTMASTER 1000



High printing speed alone is not enough. In this unique machine the operator can take full advantage of the maximum speeds due to the simple operation and its many automatic features.

Without doubt the Printmaster 1000 offers a combination of speed and quality printing which has never been approached before.

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also eliminates the need for protective painting. The unit is supplied ready for immediate operation, merely requiring to be coupled up after the ground has been suitably levelled. Since the pond basin is an integral part of the tower, no concrete or steel tank and foundations are necessary.

The tower operates on the induced-draught principle, a fan and motor, mounted on the canopy, expelling the air from the top at a high velocity. The cooling air entering at the foot of the tower at a relatively slow speed is circulated evenly over the base area and throughout the interior. The packing is of the "film-flow" type, providing the maximum possible heat transference in a small space, and is composed of a number of horizontal trays of parallel laths, each layer being at right-angles to the trays immediately above and below it. The water is discharged from spreader troughs running along the entire length of the tower and flows down the grid packing, changing direction through 90 deg. every 2 in. down the whole depth of the tower. Thus, a continuously changing film of water meets the ascending air, without obstructing its course, and, as no drops are formed, loss of water by entrainment is negligible. The internal packing is made of impregnated timber and is proof against attack by all known forms of wet-, dry-, and soft-rot organisms.

SMALL LABORATORY STIRRER

Designed for general scientific and laboratory use, the new Type RZR laboratory stirrer developed by Jones & Stevens Ltd., of Littlemore, Oxford, weighs only 5 lb and provides six infinitely variable speed ranges, one range being obtained with a high-speed shaft and the other five with a low-speed shaft, offset at right-angles to the high-speed shaft and brought into operation by turning the stirrer through 90 deg. The speed range of the high-speed shaft is 110 to 1700 rpm, and of the low-speed shaft 3 to 45 rpm, 7 to 105 rpm, 10 to 150 rpm, 14 to 210 rpm, and 17 to 255 rpm. Close and accurate control of both shafts is afforded by a knob and a clearly readable scale at the side of the stirrer.

The 50-W motor is of the single-phase, squirrel-cage, induction type, totally enclosed and mounted in ball bearings. This design ensures complete elimination of any danger of sparking and possible explosion of any products being stirred. The shafts are hollow and the height of the stirring rod itself can easily and quickly be adjusted by opening with a special key a chromium-plated chuck, which is fixed to the shaft by a grub-screw and can easily be released for transfer from one shaft to the other.

RADIOACTIVE ISOTOPES FOR IDENTIFYING STEEL CASTS

The use of isotopes for the identification of steel casts has recently been introduced on an industrial scale in Sweden by Sandviken Jernverks AB, Sweden, in connection with the production of tubes for two heat exchangers for Sweden's first commercial atomic reactor, to be erected at Farsta, south of Stockholm.

To obtain a guarantee against confusion of material during the long chain of manufacture, AB Atomenergi, official contractors to the Swedish Atom Energy Board, prescribed that the completed tubes should either be subjected to a 100% analysis control or, alternatively, that isotope branding should be used during the process of manufacture. As 100% analysis control (e.g., spectroscopic, magnetic, or chemical) was impractical, owing to the time required per tube for an analysis, Sandviken chose the method of isotope branding. In consequence, to each melt of 4·5 tons, about 5 grams of radioactive tantalum 182 isotope was added in the ladle during casting. This isotope has a half-life of 111 days, and processing of the eight melts of the isotope-branded steel cast has so far gone according to plan, radiation from the ingots being of sufficient strength to permit identification of the tubes after nine months. On the other hand, the intensity of radiation from the ingots is so low that no special precautions need be observed in the handling of the material during rolling and other operations.

This method of branding, which provides a considerable saving in time and cost, is also considered of practical interest in the production of high-pressure tubes for superheaters and steam power-plants.

UNIVERSAL-POSITIONING HOLDER FOR THROW-AWAY CARBIDE TOOLS

A new universal-positioning carbide-tool holder, announced by Maxwell Industries, Inc., of Ashtabula, Ohio, makes it possible to combine the economy of carbide throw-away inserts with the advantages of universal positioning for all metal turning and shaping operations, and does away with the need for having several fixed angle holders in different sizes. In addition, it speeds up the work of the operator, as it eliminates the need to change holders from right-hand to left-hand or straight during a sequence of operations. When indexing the insert, it is not necessary to disturb the set-up by taking the holder out of the machine. All that is required is to loosen the cap assembly, after which the carbide tool is indexed and the cap retightened, the holder remaining on centre and further speeding up operations.

Designated the "Throway", the new tool-holder is ruggedly built, with a forged-steel shank, anvil, and clamping-cap assembly, the cap screw having a nylon insert for rigid locking. It is possible to position the tool to any desired angle, and any grade of carbide required for the job can be used without investing in additional holders. High-speed square or round tool bits or boring bars can also be used with the simple addition of a standard clamping cap for each grade and shape of cutter.

EXTRUDING AND BLOW-MOULDING MACHINE FOR HOLLOW PLASTIC CONTAINERS

Intended for use with polythene or other suitable plastics, the new "Blow-Master", manufactured by the Amigo Machine Co. Ltd., of London, N.W.10, is a fully automatic combined extrusion and blow-moulding machine which is capable of producing hollow containers, bottles, or jars in sizes up to 3½ in. diameter and 6 in. high at a rate of up to 800 items per hour, depending on their size, weight, and shape, and also enables the inside of necks to be moulded.

As distinct from other extruding and blow-moulding machines, the Amigo machine, which has been granted a British patent, makes use of a central platen carrying a mould-half on each face and moving between two opposing mould-halves mounted on stationary platens. The central platen, to which is attached a special cutting device, cuts and carries a length of plastics tube from the extruder with each movement to the left or right. As each mould closes, air is blown into the enclosed tube, which expands in all directions into the mould, thus forming the desired container. During each blowing operation, another tube is being extruded and, on reaching a predetermined length, the platen crosses to the other side, whilst the previously formed container is ejected from the open mould. Two identical moulds can be used or, where differently shaped articles have the same colour and similar weight, these can be conveniently made by using appropriate moulds. This process makes use of the

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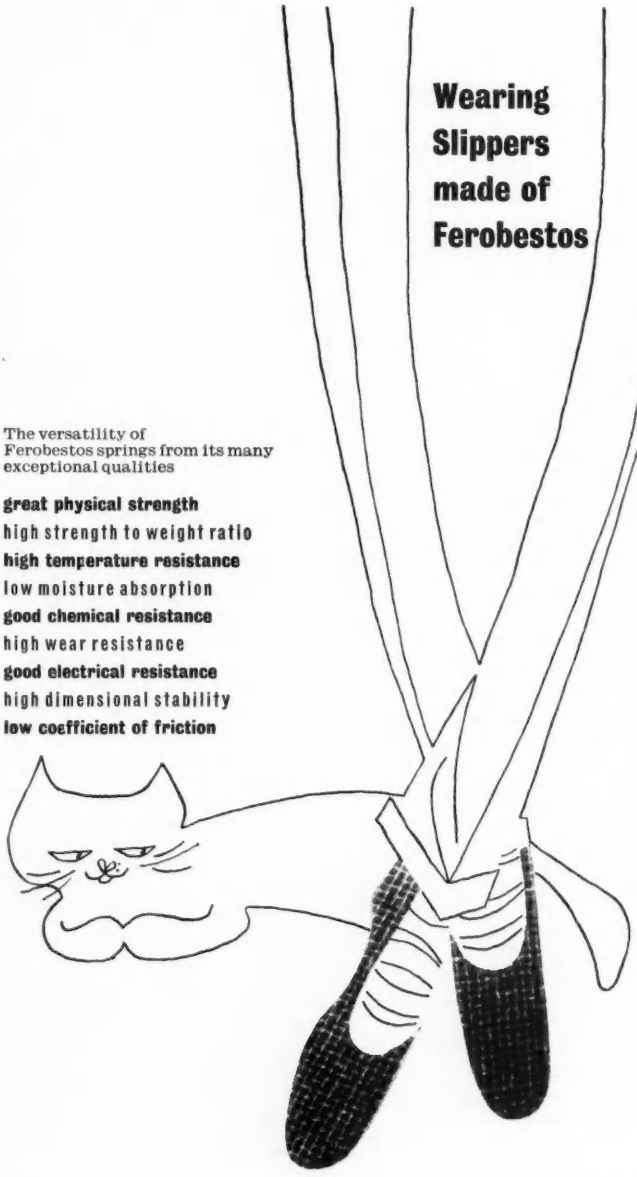

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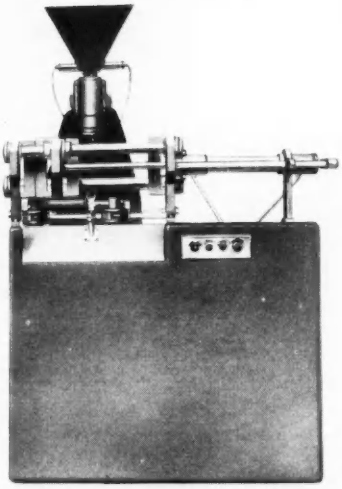
cooling time of one container to extrude the next and is virtually continuous, resulting in a great saving in production time.

The machine is fully automatic, the blowing and extrusion process being controlled by transistorized photo-electronic equipment, and the completed containers being blown to the front of the machine, which is guarded by a transparent shield and an interlock switch. Controls and signals are grouped on the front of the machine, and panels are attached with quick-action fasteners for easy access during maintenance. Tool-setting is very rapid and easy, guide pins being unnecessary, while waste of material is minimized by the proximity of the mould to the extrusion die and the repeat accuracy of the photo-electronic equipment. A warning



light from the hopper obviates the possibility of running empty, with the attendant necessity for resetting, and the press tie-bars have leather bellows covers to obviate the entry of abrasive dust and to protect them against accidental damage. Rapid starting from cold is ensured by sensible overrating for heating, and the whole equipment is free from noise and vibration during operation.

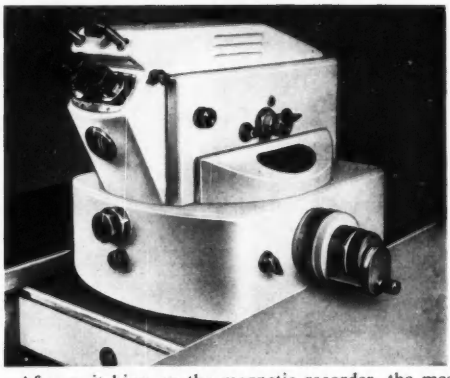
NUCLEAR-TRACK MEASURING MICROSCOPE

The nuclear-track measuring microscope made by Carl Zeiss Jena is a precision instrument in which particular attention has been paid to reducing to a minimum all errors having a detrimental effect on scatter measurements. At the same time, careful arrangement of the working and measuring elements greatly facilitates operation and thus increases speed. Irregular deviations from the straight movement, i.e., small curvatures or so-called "noise", are kept as low as possible. This stage noise depends on the focal length of the cell and, in the new instrument, ranges from 0·005 to 0·02 μ, the noise of the objective movement being of the same order. Both movements can be checked at any time by means of a built-in interferometric checking device, part of which is located in the instrument. The microscope rests on a special table which accommodates all accessories, including the magnetic recorder and electrical control panel. Any plate not exceeding 195 mm diagonally can be measured free from dead spots, the absolute limit for the width of the plate being 300 mm.

The instrument is energized by operation of a mains switch, above which are located the condenser pinion head and the pinion head for controlling movement in the *Y*-direction, a microphone, a binocular viewing attachment, and an adjustable head-rest. On the right-hand side of the microscope are located a locking knob for the head-rest, pinion heads for angle measurements and height adjustment, and a control knob for the oil pump for regulating the supply of immersion oil. Behind this control knob is the switch for the main lamp and interference lamp. The pinion head for the *X*-movement has behind it an adjustment permitting various cell focal-length settings from 50 to 500 μ. In addition, there is a device for switching an auxiliary lens into the path of the illumination, so as to make it possible to illuminate the field of vision of the measuring objective, and that of the viewfinder objective, without moving the condenser.

In keeping with the requirement that a lens system used for nuclear-track measurement should have the greatest possible aperture, combined with a large object distance, the instrument incorporates for measuring a monochromatic ×50 lens system with an aperture of f:1·35 and an object distance of 0·6 mm. In addition, a special achromatic ×50 lens system, with an aperture of f:1·0 and an object distance of 1·9 mm, is provided. Also supplied with the instrument is an apochromatic viewfinder lens system (×15), with an aperture of 0·30, used at an object distance of 5·0 mm. The magnification range with the viewfinder objective is from ×160 to ×250, and with the measuring objective from ×800 to ×1250.

For measurements of scatter, the track is aligned parallel to the lateral or *X*-direction, the nuclear-track plate in this case being fixed on a metal plate which can, as required, be magnetically coupled for a rotating movement centred on the optical axis or for lateral movement. In principle, the microscope ensures separation of the measuring procedure from the reading procedure, i.e., the latter can only be read after switching on the scale illumination, the measured values appearing in the same binocular tube and eliminating any possible subjective errors. After switching on for dial observation, one scale for adjustment of the objective, i.e., depth adjustment in the *Z*-direction, can be read in the field of vision, another scale on the right being for scatter measurement. The measuring interval on both scales is 0·1μ but, as one-fifth of an interval can be estimated with accuracy, a reading accuracy of 0·02μ is obtained. On a scale in the lower part of the field of vision is marked an interval of 0·1 deg. and, with a vernier, 0·01 deg. can be read.



After switching on the magnetic recorder, the measured values are recorded orally on tape through the microphone. In this way, the operator is never obliged to look away from the microscope during an entire measuring series, eliminating any need to re-accommodate or adapt his eyes for reading or writing measurements. As an example of the efficiency of this instrument, it is stated that measurements of a meson with an energy of 10^{10} eV have been made in 1 hr with an accuracyof 3%.

RESISTANCE TO CHEMICAL ATTACK

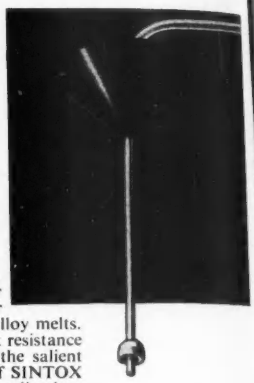
material answer to design problems

Sintox Technical Advisory Service

This service is freely available without obligation to those requiring technical advice on the application of Sintox Industrial Ceramics. Please write for booklet or any information required enclosing blue print if available.

Sintox—an alumina ceramic—is resistant to corrosive atmospheres, solutions and conditions.

Sintox is unsurpassed as an electrical insulator, and its properties also include good thermal conductivity and mechanical strength. Its characteristics are such that Sintox can be of service in the Electrical, Electronics, Mechanical and Nuclear Engineering industries.



Edwards Instruments Ltd. selected SINTOX for their 'Telegas' probe assembly for aluminium and aluminium alloy melts. Its qualities of thermal shock resistance and chemical inactivity are the salient features of SINTOX in this application.

STAS

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NEWS OF THE MONTH

PERSONAL

Mr. C. R. Wheeler, C.B.E., has been elected a director of Associated Electrical Industries Limited.

Mr. E. Seymour-Semper, M.I.Mech.E., has been elected president of the Institute of Welding for 1959/60 and **Mr. W. Barr, O.B.E., A.R.T.C.,** and **Mr. E. Fuchs, M.A., A.M.I.Mech.E.,** have been elected vice-presidents.

Mr. A. Hillier, O.B.E., chairman and managing director of Sperry Gyroscope Company Limited, has retired after 43 years service with the company.

Following the transfer of control of Sealanco (St. Helens) Ltd. to Expandite Ltd., **Mr. T. Pooley** has been appointed chairman, **Mr. G. Bussey** managing director, and **Mr. A. Cathcart, F.C.I.S., Mr. R. L. Myatt,** and **Mr. C. R. Pearce** directors of Sealanco (St. Helens) Ltd.

Mr. E. H. Curtis, B.Sc., has been appointed general manager of Carbide Industries Limited, a member of the British Oxygen Group.

The Windsor Group of companies announce that **Mr. R. E. G. Windsor,** managing director of the group, has also been appointed chairman. **Mr. A. Dennis** has resigned, owing to ill health, from all the boards of the group and has relinquished all his executive positions.

Sir George Thomson, Master of Corpus Christi College, Cambridge, has been elected president, **Dr. J. M. A. Lenihan** vice-president, **Dr. J. Taylor** honorary treasurer, **Professor F. A. Vick** honorary secretary, and **Dr. V. E. Cosslett** and **Mr. L. Rotherham** ordinary members of the board of The Institute of Physics.

Mr. L. S. Yoxall, managing director of Foxboro-Yoxall Limited, has joined the board of directors of The Foxboro Company, of Foxboro, Mass., U.S.A.

Mr. F. Cartwright has been appointed project engineer of The Bronx Engineering Co. Ltd.

Mr. G. R. J. Hallam has been appointed a director and works director and **Mr. C. E. Lowndes** works manager of H. W. Kearns & Co. Ltd. **Mr. O. Rendell** has resigned as works director while remaining a director and consultant of the company.

Dr. J. T. Kendall, M.A. (Cantab), Ph.D. (London), F.Inst.P., A.R.I.C., A.M.I.E.E., F.R.S.E., has been appointed general manager (marketing) and **Dr. J. Powell** general manager (technical) of Texas Instruments Limited.

Mr. R. W. Storey, F.R.S.A., Assoc.I.E.E., M.A.S.E.E., has been appointed managing director of Pelapone Engines Limited, of Derby, a member of the Steel Group of Companies, **Mr. W. Speight,** former managing director, has retired after twelve years of service on the board of the company.

OBITUARY

It is with deep regret that we announce the following deaths:

Sir Frederick Pickworth, chairman of the English Steel Corporation Limited, on July 14, at the age of 69.
Mr. Archibald H. Langford, director and general manager of Heenan & Froude Limited, on July 19, at the age of 64.
Mr. L. K. Everitt, a director of Edgar Allen & Company Limited, at the age of 57.
Mr. W. E. Watson, M.B.E., works director of Smith Aviation Division, on July 14, at the age of 56.

BUSINESS NOTES

Hess Products Limited and the **Chemical Division of Armour Chemical Industries Limited** have been merged under the name of **Armour Hess Chemicals Limited,** of which half of the share capital is controlled by Armour and Company, of Chicago, and the other half by U. K. interests, including a substantial proportion by **Associated Chemical Companies Limited.** The board of the new company is as follows: Mr. A. Henderson, chairman; Mr. N. Hess, managing director; Mr. J. T. Barrie, Mr. J. W. R. Hudson, Mr. M. E. Lewis (U.S.A.), Mr. E. J. McAdams (U.S.A.), Mr. M. K. Schwitzer, and Mr. E. W. Wilson (U.S.A.).

Streamline Filters Limited have moved to new premises at Henley Park, Guildford, the headquarters of the parent company, Vokes Limited.

Stanley Howard Ltd. have been appointed sole selling agents in Great Britain for the whole range of machine tools manufactured by **Eugen Weisser & Co. K.G.,** of Heilbronn/Neckar, Germany.

Stedall Machine Tool Co. have moved into more spacious premises at 192/208 Pentonville Road, London, N.1. (Tel: TERminus 3699).

An agreement has been signed between **North American Aviation Inc.,** acting through their Atomics International Division, of Canoga Park, Cal., and **The English Electric Co. Ltd.,** of London, providing for collaboration between the two companies in the field of organic liquid-cooled reactor systems.

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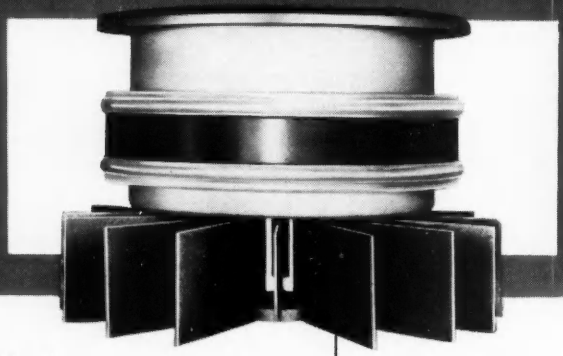
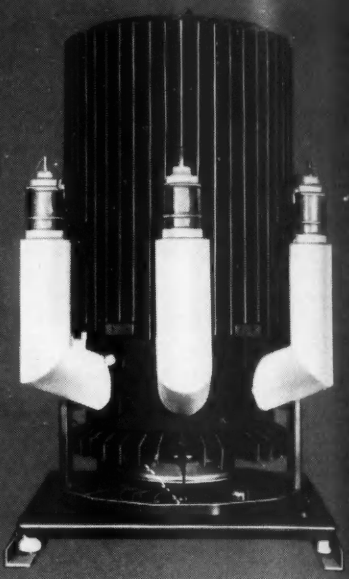
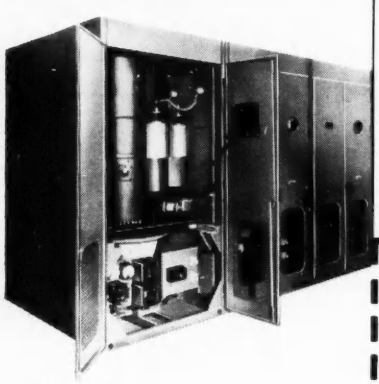
NILO K*–PORCELAIN SEALS mean better control of production





(Above)
The Cathode Assembly of an English Electric steel-tank rectifier showing the sealing rings of Nilo K. Oven heating during evacuation is needed to remove gas in the materials of construction before sealing. Nilo K to porcelain seals speed up this process by allowing higher degassing temperatures.

Research into the problems of sealing metal to porcelain enabled The English Electric Co. Ltd. to improve both their production methods and the performance of their sealed steel-tank mercury-arc rectifiers. Their Nilo K-porcelain seals will withstand higher temperatures than those permitted by the type of seal formerly used. Processing temperatures can therefore be raised, production time reduced and stricter control exercised over manufacturing operations. A higher operating temperature is also permissible. Nilo K, a nickel-cobalt-iron alloy, is one of the range of Wiggin alloys developed for glass-metal seals. These alloys match the expansion of various types of glass and are also used for many other components where a low, controlled rate of expansion is necessary.



(Above)
A 1,500 kw, 600 volt, English Electric rectifier equipment for a tramway.

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HENRY WIGGIN & COMPANY LIMITED, WIGGIN STREET, BIRMINGHAM 16

W. Canning & Co. Ltd., of Birmingham, have acquired a holding in an Australian company, **Lawrence Smith & Co. (Pty) Ltd.**, of Sidney, with whom they have been closely associated for over 50 years. The name of the Australian company is to be changed to **Lawrence Smith & Canning (Pty) Ltd.**, with head office and warehouses in Sidney, and a branch in Melbourne.

Chapman & Hall Ltd. have been appointed sole agents for the U.K. and Europe of **John Rider (Publisher) Inc.**, of New York. They will also act as sole agents for the U.K., Europe, and the British Commonwealth for **Consultants Bureau Inc.** and **Plenum Press Inc.**, both of New York.

The Churchill Machine Tool Co. Ltd. have completed a new 16-mm sound film in colour featuring the company's Model " NB " horizontal-spindle surface-grinding machine. The film, entitled " Precision Plus Production ", may be obtained on free loan from **Sound Services**, of Wilton Crescent, Merton Park, London, S.W.19.

Baldwin Instrument Company, of Dartford, Kent, have changed their name to **Baldwin Industrial Controls**, in order to reflect the company's activities in the field of non-contact thickness measuring and control of materials in continuous production, as well as in the field of control and automation equipment for a wide range of industries.

Amber Chemical Industries Ltd., of Albemarle Street, London, S.W.1, have been appointed sole distributors and licencees in the U.K., Eire, South Africa, Australia, and New Zealand for all products of **D. A. Stuart Oil Co. Ltd.**, of Chicago and Detroit (in association with Canadian D. A. Stuart). The products include soluble and cutting oils, liquid cutting and grinding compounds, hydraulic fluids, drawing and stamping compounds, and lubricating oils, greases, and bases.

Matthews & Yates Ltd., manufacturers of fans and air-conditioning equipment, have transferred their Birmingham offices to Smithfield House, Digbeth, Birmingham 5. (Tel: Midland 7284).

The Lewis Spring Co. Ltd., of Redditch, have moved to new premises at Studley Road, Redditch, where their new factory and offices occupy an area of 30,000 sq ft on a 10-acre site.

E. P. Barrus (Concessionaires) Ltd., of Brunel Road, Acton, London, W.3, have been appointed sole concessionaires in the U.K. and Eire for Greenfield taps and dies.

Flexible Drives (Gilmans) Ltd., of Carlton House, High Street, Smethwick, Staffs., have been appointed sole distributing agents for " Tyrolit " profile-grinding wheels and shapes and " Tyrolit " cutting-off discs in the U.K., India, Australia, New Zealand, Eire, and all colonies of the British Commonwealth.

British Industrial Gases Limited, of Enfield, announce that they have concluded an aggreement with the **Harris Calorific Company,** of Ohio, U.S.A., whereby the British company will manufacture oxy-fuel gas cutting equipment to the American company's designs. The agreement allows British Industrial Gases to export this equipment to all countries, except Canada, Australia, and South Africa.

The headquarters of the **Firth Cleveland Group** have been transferred to Stornoway House, Cleveland Row, London, S.W.1. (Tel: WHItehall 2166).

Cambrian Wagon and Engineering Co. Ltd., a subsidiary of **Powell Duffryn Ltd.**, have changed their name to **Powell Duffryn Engineering Co. Ltd.** Over recent years, the company have diversified their interests and, whilst remaining specialists in all forms of railway rolling stock, have established themselves in the manufacture of equipment for the petroleum, chemical, and allied industries, and in a wide field of heavy precision and structural engineering.

Metal Industries Limited announce that they have acquired 95% of the issued share capital of a French company, **Olaer France Société Anonyme,** of Paris, manufacturers of hydraulic accumulators, servo-mechanisms, shock absorbers, and similar equipment.

The Associated Chemical Companies Group have erected at their Eaglescliffe works a new plant for the production of sulphuric acid. The work was carried out by **The Power-Gas Corporation Limited,** of Stockton-on-Tees, who erect contact sulphuric acid plant to the design of **Chemibau, Dr. A. Zieren, G.m.b.H.,** of Cologne.

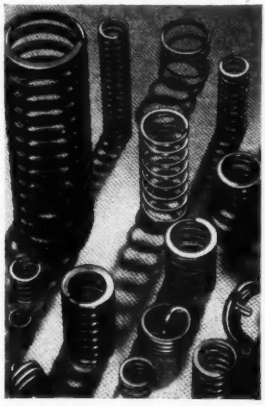
CONTRACTS

The Industrial Valve Division of Siemens Edison Swan Ltd. have received an order totalling £12,000 from Murphy Radio Ltd. for the supply of a new type of valve specially designed to operate in the lightweight portable transmitter-receiver sets now being manufactured by Murphy Radio Ltd. for the Ministry of Supply.

Rolls-Royce Limited, acting on behalf of Aerolineas Argentinas, have placed an order with Heenan & Froude Limited, of Worcester, for a complete jet-engine test plant. The test plant will be initially arranged to take the Avon engine, but will be capable of taking others of up to 30,000-lb thrust, if required.

A further order, worth approximately £30,000, has been received by the Gresham Transformer Group, of Hanworth, Middlesex, for the supply of a number of power transformers to public-service authorities in New Zealand.

A.E.C. announce that negotiations have been successfully concluded for a large engine order from Finland. The order totals 500 units and delivery is to be made over a period of one year. These engines will be installed in trucks and buses manufactured by Vanajan Autotehdas Oy., of Helsinki.



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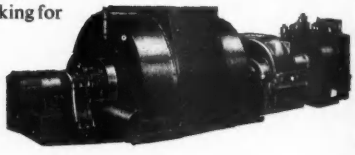

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The Head Wrightson Machine Co. Ltd., of Middlesbrough, a subsidiary of Head Wrightson & Co. Ltd., have received an order from Davy & United Engineering Co., of Sheffield, for one roller leveller to handle cold plates up to ¾ in. thick and another roller leveller to handle hot plates up to 1½ in. thick. These levellers will form part of the new plate mill which is to be installed at the works of Consett Iron Co. Ltd. The total value of these two machines, together with their associated roller tables, is about £200,000.

Ferranti Limited announce that they have received an order worth approximately £385,000 from the Central Electricity Generating Board for two 310,000-kVA, 3-phase, 50-cps double-wound transformers for installation at Blyth "B" Power Station, Northumberland.

To aid efficiency and meet growing demands on their ground organization, British European Airways have placed an order with E.M.I. Electronics Ltd. for an "Emidec 1100" electronic computer, costing over £250,000. When completed, the computer will be one of the largest data-processing systems in this country.

An order valued at approximately £400,000 has been placed with The General Electric Co. Ltd. by the Central Electricity Generating Board for the whole of the equipment for a 9-bay extension to the 132-kV substation at Willenhall.

A contract valued at over £1,000,000 has been awarded to Taylor Woodrow Construction Ltd. by the Central Electricity Generating Board for a hydro-electric project at Cwm Rheidol, near Aberystwyth, Cardiganshire.

Brookhirst Igranic Limited, a Metal Industries subsidiary, have been awarded a £50,000 contract by the Pulsometer Engineering Company Limited for control gear for the Baghdad main drainage scheme.

RADIATION-MONITORING AND TRACER SERVICE

The first commercial radiation-monitoring and tracer service in the U.K. has been launched by Ekco Electronics Ltd. to cater for the ever increasing use of isotopes in all branches of industry, medicine, and scientific research. The service offered falls broadly into three groups, i.e., (1), helping industry to fulfil the requirements of the impending Factories (Ionising Radiations) Special Regulations and including carrying out site surveys and testing sources of radiation on the premises of users of industrial nucleonic equipment, such as thickness and level gauges, X-ray machines, etc.; (2) a specialized service offered to public-health authorities and including the measurement of radioactivity in air, water, sewage, etc.; and (3) a service for the benefit of industrial and scientific research, allowing tracer experiments to be carried out by skilled personnel without the need for purchasing the complex equipment involved.

REORGANIZATION OF DAVY-UNITED

As a result of the growth of the company, both in the range and volume of their products, Davy-United have carried out a certain degree of decentralization, involving the formation of a number of wholly owned subsidiaries, each undertaking a particular field of manufacture.

The company, previously trading as Davy and United Engineering Company Limited, have become the holding company of the group, with the new name of Davy-United Limited. At present, two new subsidiaries have been formed, the first of which is called Davy and United Engineering Company Limited, who will carry on all the

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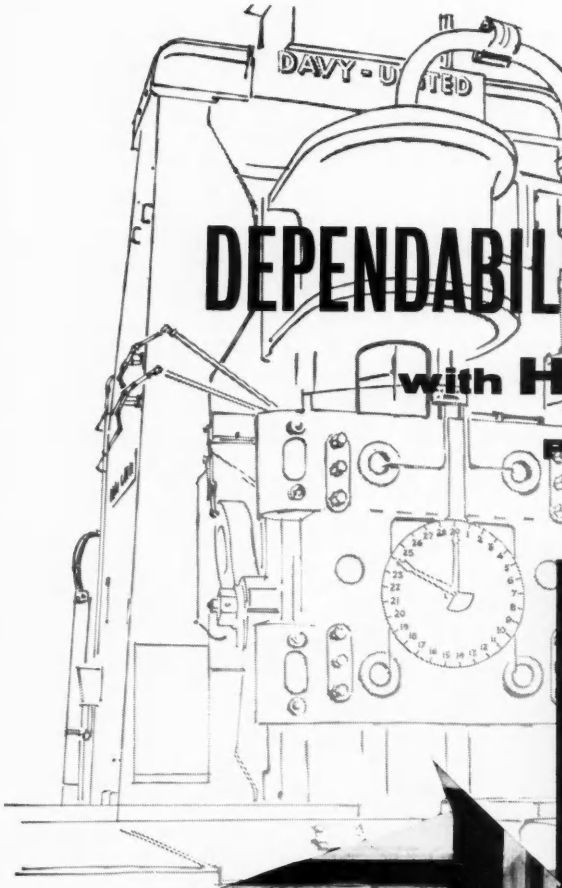

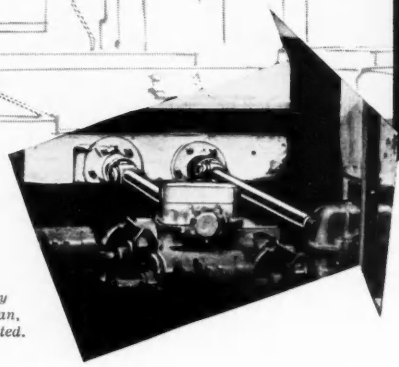

* *Photographs by courtesy of Dorman, Long & Co., Limited.*

Well known in the Automotive and Railway Industries, Hardy Spicer are now supplying in increasing quantities Propeller Shafts and Universal Joints for other engineering applications. Typical of these are Drive Shafts for the Davy-United Bloom Shear installed at the Lackenby works of Dorman Long & Co., Ltd. The shafts operate on the moving sideguards of the front depressing table which are adjusted to various openings to take the size of the Universal Beam being rolled. The Bloom Shear is of the upcutting hydraulically operated type with a capacity of 1,350 tons.

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main engineering activities of the group. This subsidiary will comprise the Darnall works at Sheffield (excluding the instrument shops), the Glasgow works in Bridgeton, and the construction division at Brantwood, Sheffield. The second new subsidiary is called Davy and United Instruments Limited and will undertake the work at present handled by the instrument division in the development and manufacture of a range of electronic- and radiation-type instruments for the automatic control of rolling mills and other steelworks processes, industrial weighing, and numerous other applications.

The manufacture of rolls and steel castings will continue to be carried out at Billingham, Co. Durham, by Davy and United Roll Foundry Limited, also a wholly owned subsidiary of the parent company.

NEW I.C.I. PLANT FOR THE PRODUCTION OF POLYESTER FILM

The Plastics Division of Imperial Chemical Industries Limited is to erect a new plant near Dumfries for the manufacture of "Melinex" polyester film. The new plant will eventually have a capacity of about 2000 tons per annum. I.C.I. have been producing polyester in small quantities at a pilot plant at Welwyn Garden City, Herts., since 1954. While the output of this pilot plant has permitted only a little more than market evaluation, the new plant will not only satisfy all immediate requirements in this country, but will also enable the company to build up an export trade in this polyester film.

CREEP INFORMATION CENTRE AT THE NATIONAL ENGINEERING LABORATORY

In response to requests from manufacturers and users of high-temperature materials, a Creep Information Centre is being set up at the National Engineering Laboratory (formerly Mechanical Engineering Research Laboratory) at East Kilbride, so that industrial designers can more readily obtain data on the strength of high-temperature materials. The main object of the centre will be to collect and tabulate all the available data on the creep and rupture properties of high-temperature materials, and the scheme will later be extended to fatigue and other mechanical properties of these materials; information about test procedures and testing machines and data on foreign materials may also be included.

All firms and research organizations concerned with the production or use of high-temperature engineering materials are invited to participate in this scheme and to write to the Director, National Engineering Laboratory, East Kilbride, Glasgow.

SYMPOSIUM ON ELECTROMETALLURGY IN ITALY

The Electrometallurgical Centre of the Italian Metallurgical Association (AIM) is organizing in the spring of 1960 a symposium in Milan on the electrolysis of molten salts and the production of special non-ferrous metals by electrothermic methods. The symposium will be followed by visits to research institutes and metallurgical works. All reports and communications in connection with this symposium should be sent to the Secretary (AIM), 16 Via Moscova, Milan, Italy.

INTERNATIONAL PLASTICS CONGRESS IN AMSTERDAM

Sponsored by the Association for the Advancement of the Knowledge of Materials, the Royal Institute of Engineers, and the Royal Netherlands Chemical Federation, an international congress will be held in Amsterdam from October 10 to 12, 1960, on the technology of plastics processing. Professor Dr. A. J. Staverman, of Leyden University, acts as president of the congress committee, and the organization of the congress has been entrusted to N. V.'t Raedthuys, of 5 Tesselschadestraat, Amsterdam, where the secretariat of the congress will also be housed.

NEW TECHNICAL BOOKS

Mechanical Design and Analysis. By R. R. Slaymaker. 432 pp., 222 illustrations. Publishers: John Wiley & Sons, Inc., New York, and Chapman & Hall, Ltd., 37 Essex Street, London, W.C.2. Price: 76/–.

Based on more than thirty years of experience in teaching engineers, Professor Slaymaker's belief is that a theory is more readily seen from the vantage point of a special case. For this reason, he has adopted an unusual approach to his subject, inasmuch as, because theories are developed for the purpose of solving problems, he sees no reason to devise problems simply as illustrations, but considers it preferable to designing for problems that actually need to be solved. Consequently, most of this book is concerned with just such a selection of industrial case studies, representing a wide and relatively recent selection from situations over the past twenty years.

The analysis pertinent to each problem is written into the projects in each case, making them clear and co-ordinated. These design situations create a need for theory and have a variety of solutions. In addition, special emphasis is placed on general topics essential for machine designers.

Worked Examples in Applied Mechanics. By W. C. Durney, M.I.Mech.E., A.M.I.P.E. 262 pp., 122 illustrations. Publishers: Sir Isaac Pitman & Sons, Ltd., Parker Street, Kingsway, London, W.C.2. Price: 12/6.

By the judicious selection of a series of worked examples, offering a fairly comprehensive range of solutions, this useful book will undoubtedly enable students to expand their knowledge and applications of the principles of Applied Mathematics as laid down in the more standard types of treatise.

The various steps set out in the calculations are given in considerable detail because, as the author points out, what may be obvious to a lecturer can often be troublesome to a student. The examples themselves have been selected from established examination papers and illustrate the different facets of the subject likely to be encountered. In this connection, it may be said that, in some parts, sections already dealt with in a previous example are repeated. This procedure has, however, been adopted deliberately with the object of emphasizing the fact that Applied Mechanics is based on certain fundamentals which can be applied in a variety of ways.

Basic Geology for Science and Engineering. By Edward C. Dapples. 620 pp., 247 illustrations. Publishers: John Wiley & Sons, Inc., New York, and Chapman & Hall, Ltd., 37 Essex Street, London, W.C.2. Price: 76/–.

Beautifully illustrated and presented, this excellent book familiarizes readers with the techniques of geologic interpretation and reconstruction of former geologic conditions and, by exploring the basic tenets of physical geology, establishes a clear understanding of the processes involved and of sediment and rock types.

Professor Dapples uses an interesting approach to his subject by presenting physical geology in a series of chapters, each of which is dependent on those preceding. In addition, each chapter is devoted to three major themes, i.e., (1) observation and grouping of data, (2) classification of data into forms which permit expression by graphic and tabular representation to determine the existence of any measurable relationship between properties, and (3) interpretation of the relationships observed, with a view to formulating significant generalizations of the behaviour of geologic processes. Information is supplemented by numerous tables, graphs, and charts, and emphasis throughout is laid on the development of principles suitable for application, rather than on descriptions of localities where specific conditions are known to occur.

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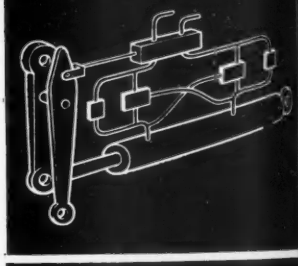

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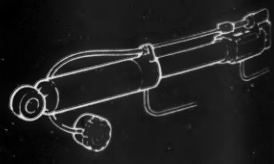

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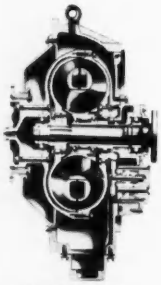

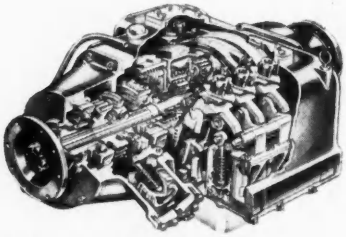

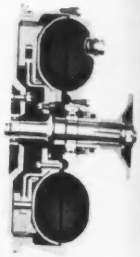

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